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PETROLOGICAL STUDIES ON SOME BASALTIC ROCKS FROM EAST GREENLAND

BY
TORSTEN KROKSTRÖM

WITH AN APPENDIX
ON THE FIELD POSITION OF SOME BASALTS INTERMEDIATE BETWEEN THE NORTHERN AND SOUTHERN AREAS IN EAST GREENLAND

BY
HELGE G. BACKLUND

WITH 5 FIGURES IN THE TEXT AND 2 PLATES

KØBENHAVN
C. A. REITZELS FORLAG
BIANCO LUNOS BOGTRYKKERI A/S
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PREFACE

In the autumn of 1937 the author undertook, at the suggestion of Prof. H. G. Backlund, an investigation of a small collection of basaltic rocks from East Greenland. The specimens were collected during Dr. Lauge Koch's East Greenland expeditions between 1929 and 1934, mainly from the neighbourhood of Hurry Fjord. Some material from Canning Land, Fleming Inlet and the innermost (western) parts of the Scoresby Sund region were, however, also included. Three chemical analyses, executed by Dr. N. Sahlbom, were placed at the author's disposal by the courtesy of Prof. Backlund.

Owing to other occupations—*i. a.* a long military service—the author was for several years able to attend only very sporadically to this work. The main part of the investigation, the results of which are now published, was carried out during the autumns of 1937 and 1941.

I. Introduction.

The rocks investigated may be classed in three different petrographical groups, *viz.* olivine dolerites, plagioclase porphyrites and basalts. The latter group, however, differs from the dolerites only texturally, whereas, as far as mineralogical and chemical composition goes, it should be included among them.

The mutual field relations of the dolerites and the porphyrites are only imperfectly known. At Kap Biot, however, a dolerite dike has been observed to cut a plagioclase porphyrite (Backlund H. G., oral communication) and this may perhaps be taken as a suggestion that within the Hurry Fjord region, too, the porphyrites are somewhat older than the dolerites, which latter are presumably of tertiary age. As will be seen, the petrographical investigation tends to confirm this conclusion as to their different geological age. A still older complex is represented by a series of alnöitic or monchiquitic lamprophyres, which will not, however, be treated more exhaustively in this paper.

II. Olivine dolerites.

These rocks, megascopically, all are of a grayish black colour, their grain varying from medium to rather fine, yet always quite distinct. The specimens subjected to examination all present, megascopically, a fresh and unaltered appearance.

Under the microscope the main minerals are found to be—in order of abundance—plagioclase, pyroxene, iron-ore and olivine. Further there are observed secondary products of several types—probably mainly after olivine—and the interstices are occupied by varying amounts of products of late crystallisation. Apatite may be present but only in very small amounts and in most specimens it is entirely wanting.

Some of the fine-grained types show a restricted number of plagioclase laths—solitary or in groups of a few crystals—up to ten times the size of the felspar of the main mass, thus attaining a slightly porphyritic or glomeroporphyritic appearance which is, however, as a rule hardly discernible in hand specimens. Disregarding these larger felspars the textural relations of the rocks as a rule vary between sub-ophitic and sub-doleritic (KROKSTRÖM 1932b). In a few cases true ophitic relations are exhibited, but the plagioclase laths then completely enclosed by pyroxene, with two exceptions (specimens 6 and 308, *cf.* p. 7), are quite subordinate in amount and, moreover, of distinctly smaller size than the average. Likewise, in sub-ophitic relations the plagioclase laths partly enclosed by pyroxene are observed to wedge out towards the central portion of the host mineral (*cf.* FENNER 1929, p. 226, BACKLUND and MALMQVIST 1932, p. 21, *ibid.* Table 2, fig. 2). These relations all seem to suggest that the plagioclase began to crystallize but little in advance of the pyroxene, an inference that is in good agreement with the fact that in most of these rocks olivine is rather subordinate in amount (*cf.* KROKSTRÖM 1932b, p. 210). Indeed the rather insignificant ophitic relations referred to above are only encountered in the specimens richest in olivine or pseudomorphs after this mineral. This matter will be further discussed on p. 7.

The following specimens have been classed as belonging to this group:

Collection BACKLUND.

1838 Liverpool Land, Hurry Fjord, E. Side of Ryders Dal. Vertical dike.

1897 Liverpool Land, N. side of Storefjord on the way to p. 58, ridge 738. Vertical dike, strike N.—S.

Collection Noe-Nygaard.

202 Fleming Inlet, Isle of Kekertak outside of the delta of Ørsted Dal. Dike cutting the Kap Biot formation, nearly vertical.
244 Canning Land, Snöviken. Alt. 25 m. Erratic boulder.
294 SW. corner of Fleming Inlet. Erratic boulder, probably derived from the uppermost part of the Kap Biot formation.
295 As 294.
307 The eastern slope of the mountain W. of the main valley in the continuation of Fleming inlet. (Desert Mts.) Alt. 145. Sill. (*Cf.* Noe-Nygaard 1934, pp. 66—67).
308 As 307, Alt. 235. Sill.
309 As 307, Alt. 320. —
311 As 307, Alt. 320. —
315 As 307, Alt. 320. —
341 Canning Land, N.W. side of Kollen, alt. 200. Erratic boulder.
441 N. of the first large delta, N.W. of Kap Biot. Vertical dike, strike N—S, width 2 m.
444 Kap Biot Alt. 800. Erratic boulder.

Collection Rosenkrantz.

5 Jameson Land, Dinosaurusklöft. Sill.
6 Jameson Land, N. of Moskusokseklöft. (Hang Mts.) Sill.

It will be noticed that in all cases, where the geological setting is recorded, the rocks belong to dikes or sills. Considering the very strong mineralogical and textural similarity of all the specimens it seems rather safe to conclude, that this relation holds good even in cases where such records are not available. Unfortunately, the azimuthal orientation is recorded only for two of the dikes, the strike in both cases being N.—S.

Petrography.

Owing to the essential conformity of all the specimens a detailed petrographical description of each of them would lead to quite unnecessary reiterations and may conveniently be substituted by a general account of their main characteristics. The variations within the group as regards size of grain, composition of the main minerals etc. are, moreover, illustrated by table I, p. 11.

Plagioclase.

Plagioclase is by far the predominant mineral. As a rule it is quite fresh, only one instance of appreciable sericitic alteration having

been observed (specimen 202). The mineral sections are generally distinctly lath-shaped, the relation between length and width averaging 5—10:1. Tabular forms are also observed but are not very frequent. Although there is a distinct tendency to idiomorphic development, clean-cut outer boundaries have rarely been accomplished and this sometimes holds true even for the occasional phenocrysts. On the contrary the plagioclase seems to have continued its growth until the last stages of crystallization, the result being in most cases contours of a slightly sinuous shape.

Twinning according to the Carlsbad and Albite laws is very frequent and sometimes so intense as to make FEDOROW stage measurements impossible in the narrower of the laths. Pericline and Baveno twinning has also been observed, the latter type, however, being exceedingly rare.

Practically all of the laths show a strongly undulose extinction indicative of compositional inhomogeneity. With a few exceptions, however, no discontinuous zoning (PHEMISTER 1934) has been observed, the exceptions being found only among the occasional phenocrysts. This normal continuous variation in composition is generally very strong and consequently it is rather difficult to ascertain the average composition of the plagioclase of these rocks. Thus for instance one continuously zoned phenocryst of specimen 295 showed a variation from 60 % An (in the centre) to 25 % (in the outermost part). In order to obtain—as far as possible—commensurable values, the optical determinations were all carried out in the centre of the crystal sections, and the composition deduced thus tends to approximate that of the material deposited in the early stages of the formation of the crystal. This approximation may, however, be rather coarse as we are not able to ascertain, whether the section examined is really passing the central part of the crystal or is only skirting its peripheral parts. In order to get even a tolerably satisfactory view of the total range of compositional variation a measurement of a very great number of individuals in each slide would be necessitated and, moreover, the determinations would have to be executed both in the central and the peripheral parts of every individual. No doubt such an exhaustive investigation would be of considerable theoretical interest but would, nevertheless, fall beyond the scope of the present paper.

In view of these considerations the plagioclase determinations have been restricted to two or three laths in every slide and the average results are given in column 2 of table I (p. 11). We find that all the values fall between 55 and 75 % of anorthite, all except four being included within the limits 65 % ± 5 %. It seems safe to conclude, then, that there is no great difference between the rocks examined, as regards

their plagioclase composition. As for the average An-content, it most probably lies about 60 %, considering that the optical determinations were all made in the central parts of the sections, i. e. in the most calcic portions.

Some tentative determinations of the composition of the phenocrysts of the slightly porphyritic types brought out no great difference between them and the average-sized felspars. It is true that the anorthite percentage of the phenocrysts tends to come out a little higher than that of the "ground mass" laths examined, but this tendency does not seem to be very strong and, considering the range of variation of the latter, certainly does not justify any conclusions whatsoever. In this connection specimen 308 is of special interest.

This specimen together with No. 6 differs from the rest in exhibiting, on a rather large scale, true ophitic relations. About one third of the rock consists of large lath-shaped or tabular plagioclases, attaining a length of sometimes as much as 5 mm. Numerous allotriomorphic pyroxene grains of about the same order of magnitude show sub-doleritic relations to the large felspars where encountering them. Olivine is represented by a considerable number of fairly large rounded grains. The rest of the rock is made up mainly of a fine-grained web of divergent-radiating plagioclase laths (average length about 0.2 mm), most of which are scattered all over the pyroxene areas in a truly ophitic fashion. Specimen 6 is very similar to n:o 308 but phenocrysts are rather sparse and olivine is represented only as relics within pseudomorphs. The texture of this rock necessarily invites speculation as to the order of crystallization. Two explanations seem to be possible.

1) Either plagioclase was for a long time the only mineral separated, except olivine, and its early-formed crystals thus had ample opportunity to attain considerable dimensions. Only at a much later stage pyroxene began to crystallize, embedding part of the "youngest" of the felspars, which were still rather small.

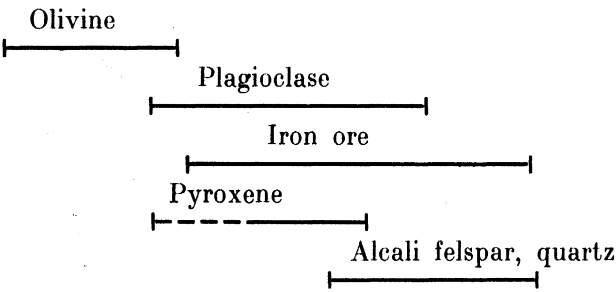
2) Or plagioclase began to crystallize but slightly in advance of pyroxene. At a stage when the laths had attained the size now shown by those of the ophitic areas, part of them were enveloped by pyroxene, further growth thus being prevented. The laths that escaped this "embrace", however, were able to continue their growth, until their present large size was attained.

It seems that a decision between these two interpretations could perhaps be made by a comparison of the two types of plagioclase as regards their chemical composition. According to the first alternative the central parts of the phenocrysts should be more calcic than the ophitically embedded laths. On the other side, if the second explanation

be valid, the composition should be much the same in both types. A couple of measurements yielded the following results:

Phenocrysts:	62, 68, 68 % An	Average 66 %
Small laths:	59, 65, 66 % An	Average 63 %

In view of the range of variation within each group these figures must be considered to indicate about the same composition in both types of felspar and thus to speak in favour of a rather early crystallization of pyroxene. As a matter of fact a contrary result would have been very much surprising as all the rocks of the group just treated are evidently very closely related and in the rest of them everything seems to indicate an essentially simultaneous crystallization of pyroxene and felspar. The general order of crystallization may be illustrated by the following diagram.



The broken part of the pyroxene line is intended to indicate that the stage at which the first deposition of pyroxene occurred may vary slightly in relation to that of plagioclase. Thus the pyroxene of most of the dolerites was first deposited at the left end of the pyroxene line above, whereas the pyroxene of the markedly ophitic specimen 308 began its crystallization only at the end of the broken line. Such a variation must no doubt be due to slightly different composition of the corresponding magmas. Now specimen 308 belongs to the same sill as several specimens (309, 311, 315) that do not show ophitic relations, which seems to suggest an inhomogeneity even within a rather restricted magma portion. In view of the necessarily very scant field data, however, speculations as to the probable cause of such inhomogeneities are bound to prove futile.

Clinopyroxene.

This mineral microscopically is of a faint brownish gray hue. It shows almost no signs of alteration except for a few specimens (202, 294, 315) where it is surrounded homoaxially by a narrow and irregular fringe of amphibole. The character of this secondary amphibole is

slightly different in different specimens. So for instance the following optical data were observed:

Specimen 202: $c/\gamma = 15°$
α colourless
γ olive green to olive brown
Birefringence medium

Spec. 294 and 315: $c/\gamma = 15°$
α colourless
β pale green
γ yellowish green
Birefringence low.

In most slides there are observed rather large amounts of ill-defined chloritic secondary products, which will be discussed below in connection with olivine. Owing to the rather close association of olivine and pyroxene it is not always possible, however, to decide whether this material has been derived from olivine exclusively or if pyroxene may also to some extent be responsible for its formation.

Simple twinning on 100 is fairly frequent. The trace of the contact plane is marked in oblique sections by a two-coloured interference stripe, in sections normal to the plane by an extremely narrow dark stripe, symmetrically bordered by two equally narrow, bright and colourless zones. Owing to the angle c/γ being in some of the crystals close to or even exactly 45°, the extinction positions in the two twinned individuals tend to be identical or almost so, only the directions α and γ are exchanged. In most cases a complete coincidence of the two β-directions is observed, as theoretically required, but very careful FEDOROW measurements in homogeneous light seem to show that this is not always the case. Now, according to FRIEDEL (1926 p. 456) the twinning law in question is an example of his "macles par pseudo-mériédrie réticulaire" having for axes [201], which implies an obliquity of 11′. This obliquity, falling in the α—γ plane, does not, however, imply any divergence between the β-directions. As a matter of fact, measurements in three different twins gave deviation angles between these directions of 4°, 5°, and 5°, corresponding to an obliquity of about 2°. Even allowing for the considerable difficulty involved in ascertaining the exact position of the optic axial plane—owing *i. a.* to the phenomena of conical refraction—and even admitting that the inaccuracy of the readings may approach the angle value just mentioned, there still remains the purely qualitative observation, that the optic axial planes sometimes do not exactly coincide. It would appear then, that the pseudosymmetrical character of the twinning may

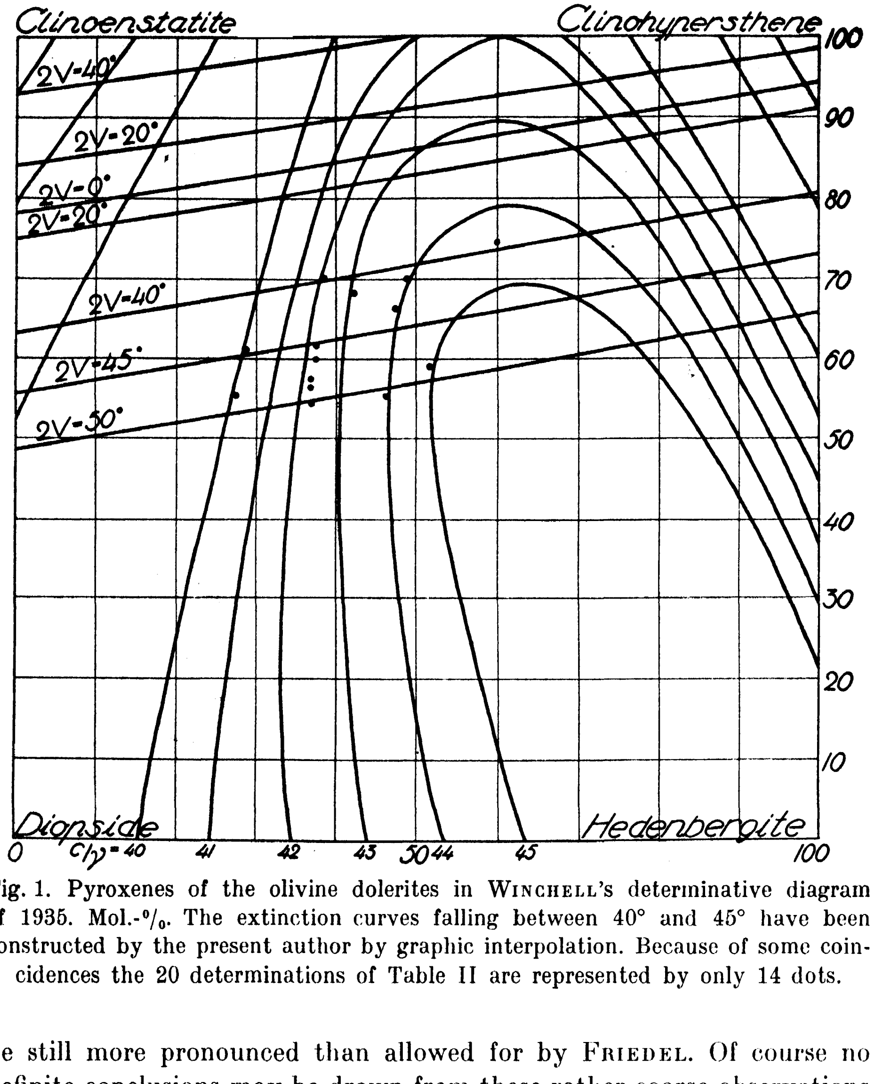


Fig. 1. Pyroxenes of the olivine dolerites in WINCHELL's determinative diagram of 1935. Mol.-%. The extinction curves falling between 40° and 45° have been constructed by the present author by graphic interpolation. Because of some coincidences the 20 determinations of Table II are represented by only 14 dots.

be still more pronounced than allowed for by FRIEDEL. Of course no definite conclusions may be drawn from these rather coarse observations but still it might be worth while to call attention to their possible significance.

The pyroxene usually shows a blotchy or undulose extinction no doubt indicating some sort of zoning, which is, however, rarely so regular as to allow an unambiguous discrimination of centre and margin. In a few cases, however, the zoning is more regular, and in two individuals the following optical data were obtained (FEDOROW stage):

Spec. 202	Centre: $2V\gamma = 47°$.	Margin: $2V\gamma = 42°$
— 5	Centre: $2V\gamma = 45°$, $c/\gamma = 40°$.	Margin: $2V\gamma = 39°$, $c/\gamma = 45°$.

The significance of these figures will presently be returned to.

Table I.

Specimen	1 Average size of felspar laths in mm	2 Anorthite percentage of the plagioclase[1])	3 Clinopyroxene 2 V	3 Clinopyroxene c/γ	4 Olivine 2 Vα	4 Olivine % Fa WINCHELL 1935
5	0.5	54	45° (centre) 39° (margin) 46°	40° (centre) 45° (margin) 42°	..	..
6	0.5	56[3])	46° 45°	42° 42°	.. ..	.. ..
202	1.5	75	46° 42°	42° —	.. ..	.. ..
244	0.5	62	42° 43°	— —	.. ..	.. ..
294	0.3	66	40° 41°	42° —	.. ..	.. ..
295	1.0	60	46°	42°	88°	18
307	1.5	65	44° 48°	— —	84°	28
308	0.4 (ground-mass) 2.0 (phenocrysts)	68	42°	43°	84° (centre) 76° (margin)	28 45
309	1.5	60	41°	44°	76°	45
311	4.0	65	43°	44°	86°	24
315	0.3	72	49°	45°	..	..
341	0.3	60	48° 48°	40° —	.. ..	.. ..
441	0.7	69	49° 48° 50°	42° 42° 42°	.. .. ..	.. .. ..
444	0.2	—	48° 46°	42° 42°	.. ..	.. ..
1838	0.3	66	43°	44°	86° (centre) 80° (margin)	24 37
1897	0.3	70	50° 49°	44° —	77°	43
Average values and maximum deviations in both directions[2])		$64\,\% \begin{cases} +11 \\ -10 \end{cases}$	$45° \begin{cases} +5 \\ -5 \end{cases}$	$43° \begin{cases} +2 \\ -3 \end{cases}$	$82° \begin{cases} +6 \\ -6 \end{cases}$	$32\,\% \begin{cases} +13 \\ -16 \end{cases}$

[1]) Mostly average of two or three individuals.
[2]) When calculating the deviations the zoned individuals were represented by the average of central and marginal values.
[3]) Phenocryst 77 %.

In order to get a rough view of the variation of the clinopyroxene the values $2V\gamma$ and c/γ were determined in a fairly large number of

sections and the results are given in column 3 of Table I. Fig. 1 shows their position within the determinative diagram constructed by WINCHELL (1935 p. 567). This diagram is not strictly applicable for the pyroxenes now under consideration, as it refers to a series free from Al_2O_3 and Fe_2O_3, whereas our pyroxenes most probably contain at least Al_2O_3 in quantities that must not be neglected. According to

Table II. Approximate composition of the clinopyroxene of the dolerites, according to WINCHELL (1935).

Mol.-%.

1	2	3	4	5
Specimen	Clino-enstatite	Ferro-silite	Diopside	Heden-bergite
5 (centre)	44	17	28	11
5 (margin)	30	44	10	16
5	38	22	25	15
6	38	22	25	15
—	39	23	24	14
202	38	22	25	15
294	43	27	19	11
295	38	22	25	15
308	39	29	19	13
309	36	34	15	15
311	34	32	18	16
315	28	31	20	21
341	40	15	33	12
441	36	20	28	16
—	36	21	28	15
—	35	19	29	17
444	36	21	28	15
—	38	22	25	15
1838	34	32	18	16
1897	30	26	24	20

WINCHELL (*loc. cit.* p. 568), however, a tenor of Al_2O_3 has rather little effect on the optic axial angle. Now, the curves for 2V make only fairly small angles with the abscissa, whereas the curves for c/γ stand almost at right angles to it. Thus it seems probable that a possible Al_2O_3-content will influence the reliability of the diagram but little, as regards the CaO-content. It is evident from fig. 1, that the scattering of the points in the vertical direction is not very strong. As a matter of fact, disregarding the point representing the margin of the zoned crystal of specimen 5, no less than 15 points out of 20 fall within the limits 60 ± 5 % of clinoenstatite + clinohypersthene and even the remainder

does not fall far outside of this interval. Further, although the optic axial angle was always determined in sections with both axes accessible, the accuracy of the result can hardly be considered to surpass $\pm 2°$, corresponding in this part of the diagram to about $\pm 3\ ^0/_0$ of Ca-free molecules. According to this diagram, then, the tenor of Ca-free molecules comes out much the same in all these pyroxenes and does not fall far from 60 $^0/_0$. The actual proportions of the four components as indicated by the diagram are entered in table II.

As is well known, however, the relations between the optical properties and the chemical composition of pyroxenes have not yet been satisfactorily established. Several of the determinative diagrams recently devised (e. g. WINCHELL 1927, WINCHELL 1935, TOMITA 1934) disagree rather markedly. This fact is brought out by table III on p. 16, which gives the composition in mol.-$^0/_0$ of $CaSiO_3$, $MgSiO_3$ and $FeSiO_3$ according to the three diagrams just referred to. For sake of perspicuoussness the three series of interpretation have also been entered into a triangular diagram, fig. 2. In the series according to WINCHELL 1927 there have also been included a few older determinations on greenlandic pyroxenes. The data in question are given by MALMQVIST (BACKLUND and MALMQVIST 1932) for some pyroxenes of dolerites mainly from Clavering Island. The average of his determinations is $2V\gamma = 47°$, $c/\gamma = 42°$, the variation being confined within rather narrow limits. The pyroxenes from Clavering Island thus fall very closely together with those now described, which is still more evident from fig. 2. In table IV on p. 16 the fundamental data of these rocks are put together.

A glance at the diagram shows that the $CaSiO_3$-values vary only rather insignificantly within each series, whereas the differences between the series are considerable. As to the quotient $MgSiO_3 : FeSiO_3$ the variation even within each series is rather wide, especially so in the series resulting from WINCHELL's diagram of 1935. The zoned pyroxene of specimen no. 5 is of special interest. Its optical properties do not allow its projection in TOMITA's diagram but both of WINCHELL's diagrams give a distinctly higher content of $MgSiO_3$ in the centre than at the margin. According to the curves of 1927 the content of $CaSiO_3$ is much the same in both portions, whereas the diagram of 1935 suggests a decrease in lime towards the margin. Now the line of chemical evolution within a crystal from its centre to its margin ought to conform with the line connecting separate crystals of early and late formation within the magma. As a matter of fact the general trend of the projective points of each series indicates a changing proportion Fe:Mg while the lime content remains fairly unchanged. From this reason it seems rather probable that the actual relations are better pictured by WINCHELL's first diagram than by the new one. Another support for this opinion

may be gathered from a study of the chemical analysis, Table V, and the question will presently be returned to.

Everything considered, then, the pyroxenes of these rock specimens seem to vary but little in composition and, especially, to have a fairly constant content of $CaSiO_3$. Their composition is rather ade-

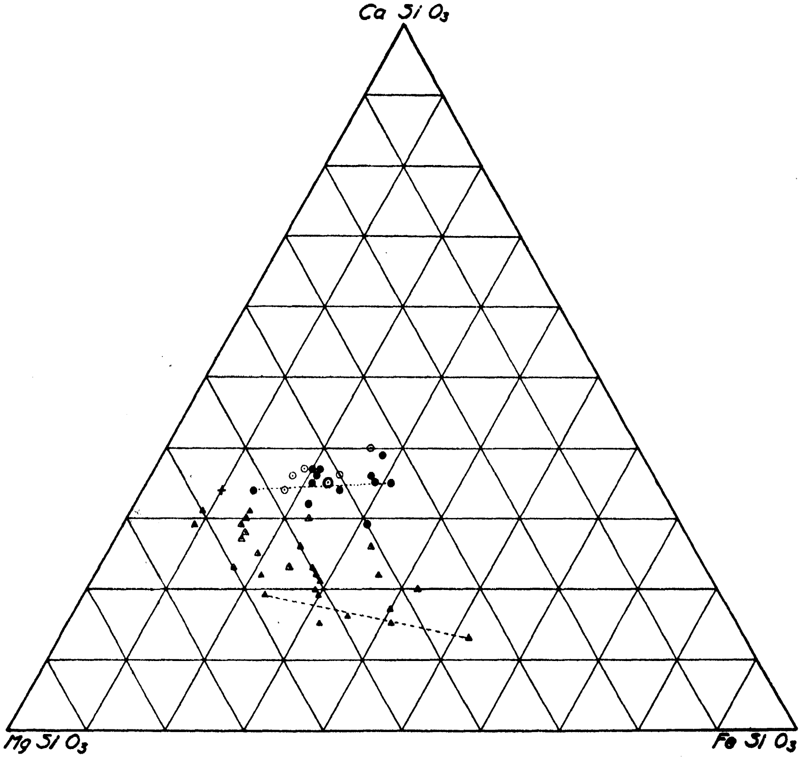


Fig. 2. Metasilicate proportions of Greenlandic pyroxenes according to WINCHELL 1927 (filled and dotted circles), TOMITA (dotted triangles) and WINCHELL 1935 (filled triangles). The dotted circles refer to determinations by MALMQVIST (1932). Some of the points represent several determinations. The points united by broken lines represent kernel (to the left) and margin of the zoned pyroxene of specimen 5. The double circle indicates the average value according to WINCHELL 1927. As regards the cross see text.

quately represented by the average value obtained. The position of this average within the triangular diagram fig. 2 moreover coincides with one projective point belonging to MALMQVIST's series. It is indicated by a heavy circle. The average composition is, however, by no means definitely ascertained, as the probable alumina content has also to be considered. As mentioned above, however, the displacement caused by alumina will most probably have taken place mainly along the isoaxial lines of the diagram, *viz.* roughly parallel to the Mg-Fe side of the triangle.

Accepting WINCHELL's statement that Al_2O_3 would tend to increase the extinction angle by 3—5°, we may further try to deduce the line of "alumina displacement". Starting from the average, which corresponds to $2V\gamma = 44°$, $c/\gamma = 42{,}5°$, the position within the triangle was calculated for a pyroxene with $2V\gamma = 44°$ and $c/\gamma = 37{,}5°$. This point is indicated by a cross. It seems probable then, that a line connecting the cross and the heavy circle would represent the *locus* of the metasilicate proportions of these pyroxenes. The higher the alumina content, the farther the average point should be displaced to the left in order to indicate the actual metasilicate proportions. It will be readily realized that an increasing alumina content would tend to influence the optical properties in the same manner as an increase in $FeSiO_3$ and a very slight increase in $CaSiO_3$. As a consequence—if our initial supposition be correct—the compositions deduced by means of the determinative diagram now under discussion ought always to give maximal values of the important quotients $CaSiO_3$:(Mg,Fe)SiO_3 and $MgSiO_3$:$FeSiO_3$.

Olivine.

Olivine or pseudomorphs after this mineral are invariably present though generally in rather restricted amounts. Mostly it occurs as equidimensional rounded grains, but a tendency to idiomorphic development may sometimes be traced, and may even be inherited by the pseudomorphs. Inclusions of other minerals have not been observed but occasionally part of a plagioclase lath may penetrate into the marginal portion of an olivine crystal.

Zoning is not very conspicuous but, where observed, always of the continuous, normal type (TOMKEIEFF 1939). Thus in two individuals the following data were obtained (FEDOROW stage):

Specimen 308	Centre: $2V\alpha = 84°$	Margin: $2V\alpha = 76°$
	28 % Fa	*45 % Fa.*
Specimen 1838	Centre: $2V\alpha = 86°$	Margin: $2V\alpha = 80°$
	24 % Fa	*37 % Fa.*

These values indicate a considerable enrichment in iron as crystallization proceeds. (Composition calculated according to WINCHELL 1933)

Column 4 of table I shows the optical angles determined and the corresponding fayalite percentages according to WINCHELL (*loc. cit.*). The results indicate a considerable range of variation but the very high fayalite percentages reported by MALMQVIST (1932, maximum value 65 % of fayalite) are nowhere met with. As is evident from table I, neither the anorthite percentages of the plagioclase nor

Table III. Metasilicate proportions of pyroxenes according to WINCHELL 1927, TOMITA 1934 and WINCHELL 1935.

Mol.-%.

Nr.	$CaSiO_3$ 1927	$CaSiO_3$ 1934	$CaSiO_3$ 1935	$MgSiO_3$ 1927	$MgSiO_3$ 1934	$MgSiO_3$ 1935	$FeSiO_3$ 1927	$FeSiO_3$ 1934	$FeSiO_3$ 1935
5 (centre)	34	29	19	52	62	58	14	9	23
5 (margin)	35	..	13	34	..	35	31	..	52
5	36	28	20	43	56	51	21	16	29
6	36	28	20	43	56	51	21	16	29
6	35	27	19	44	57	51	21	16	30
202	36	28	20	43	56	51	21	16	29
294	32	23	15	46	60	53	22	17	32
295	36	28	20	43	56	51	21	16	29
308	34	25	16	41	56	49	25	19	35
309	35	23	15	36	53	44	29	24	41
311	36	26	17	36	50	43	28	24	40
315	29	26	20	40	41	38	31	33	42
341	35	31	22	52	60	57	14	9	21
441	37	30	22	42	55	50	21	15	28
441	37	29	21	43	56	50	20	15	29
441	37	31	23	42	54	50	21	15	27
444	37	29	21	43	56	50	20	15	29
444	36	28	20	43	56	51	21	16	29
1838	36	26	17	36	50	43	28	24	40
1897	39	30	22	33	47	42	28	23	36
Average..	35	28	19	42	55	48	23	17	33

Table IV. Greenlandic pyroxenes according to MALMQVIST.

No.	2 Vγ	c/γ	Composition WINCHELL 1927 Di	Hed.	Enst.	Weight-% $CaSiO_3$	$MgSiO_3$	$FeSiO_3$	Mol.-% $CaSiO_3$	$MgSiO_3$	$FeSiO_3$
141	45	42.6	23	51	26	36	37	27	35	42	23
140	44	43	20	54	26	36	35	29	36	40	24
138	48	41.3	35	40	25	33	41	16	37	45	18
101	44	42.5	22	51	27	36	37	27	35	42	23
102	53	43.5	29	55	16	41	30	29	40	34	26
1037	48	42	30	46	24	38	38	24	37	44	19
1093	46	41	34	39	27	36	43	21	34	48	18
1467	47	42	29	46	25	38	38	24	37	45	18

the optical data of the pyroxene show any simple relations to the fayalite content of the olivine. According to my experience from other

petrologically fairly similar rocks (KROKSTRÖM 1936) it is even very probable, that by extending the measurements to a greater number of individuals, the variation within each specimen might be found to attain the same width as that now proved for the rock suit as a whole. Indeed, the zoned crystal of specimen 308 covers the whole range of variation observed, except for one determination.

In most specimens the olivine is rather strongly altered, the alteration products being of several different kinds. Most wide-spread are pseudomorphs consisting of some green, yellowish or yellowish brown material that probably, for all its variations, belongs to the rather ill-defined group of iron-rich chlorites (diabantite, delessite, ferrite, iddingsite etc.). The author, in another connection, has made a fairly detailed study of this type of olivine alteration and as most of those observations seem to be valid even for the rocks now in question the reader is referred to this treatise (KROKSTRÖM 1936, pp. 131 ff., 146, 163 ff.) for details.

Other types of alteration conform with the pilite, first described by BECKE (1893). Furthermore alteration to talc has been observed and, finally, in some specimens the olivine crystals are strongly dissected by irregular serpentine veins. All these types of alteration products are intimately associated with iron ore as fine grains or dust.

As already mentioned it is not always easy to decide unambiguously, if the fairly abundant chloritic pseudomorphs have originated from olivine exclusively. As a matter of fact one may sometimes observe relics of pyroxene within the pseudomorphs, and it would appear then that the pyroxene, too, had succumbed to the same type of alteration as the olivine. However, the two minerals, when unaltered, are often very intimately associated, olivine being enclosed or surrounded by pyroxene in a most intricate fashion. Thus it is by no means impossible that the pyroxene "relics" simply represent the remains of such an intergrowth which have been left entirely intact by the alteration affecting the olivine component. Most probably, however, both minerals were affected.

Iron ore is in most specimens rather abundant. It occurs either as irregular lumps and grains or as long narrow rods, sometimes in groups of faintly sub-parallel arrangement. The rods are predominantly found in the interstitial fillings (cf. below) but are also seen to penetrate fnto or even entirely dissect pyroxene crystals.

As a product of last crystallization there is found a rather obscure interstitial filling, that may in some specimens amount to considerable quantities. It is mainly made up of alcali felspar and quartz, sometimes in micrographic intergrowth, sometimes only to be surmised in

an almost un-individualized mass, no doubt representing glass on the verge of devitrification. In these fillings there are further observed pyroxene crystallites of the margarite type, generally more or less amphibolized, iron rods of the type just described and, finally, in most specimens, scattered all over the basis, a large number of infinitesimally fine green or brown scales, probably representing biotite, ferrite and/or amphibole. Calcite may be present in considerable amounts.

Chemistry.

In table V a chemical analysis of one of the olivine dolerites is given. The specimen analyzed may be considered as a fairly good representative of the rock suit, except that it displays true ophitic relations to an extent matched only by specimen 308 (cf. p. 7). The rock is remarkably fresh except for some quantity of yellowish-brown chloritic matter, representing olivine pseudomorphs. Fresh olivine is encountered only as rather insignificant relics within these pseudomorphs. A few idiomorphic plagioclase phenocrysts (average size about 1 mm.) are scattered all over the fine-grained ophitic ground-mass.

Table V. Analysis 1. Dolerite from sill, N of Moskusokseklöft (Hang Mts.), Jameson Land. Coll. ROSENKRANTZ no. 6.

Sp. gr. $\frac{14°}{4°}$ = 2.965 Analyst: N. SAHLBOM.

	Weight-%	Mol. prop.	Norm			
SiO_2	46.62	777	Or	3.34	3.34	..
TiO_2	2.81	35	Ab	16.24	16.24	..
Al_2O_3	14.39	141	An	28.91	28.91	Σ sal 48.49
Fe_2O_3	2.15	14	Di $CaSiO_3$	10.44	20.59	..
FeO	11.85	165	Di $MgSiO_3$	5.40		
MnO	0.24	3	Di $FeSiO_3$	4.75		
CaO	11.40	204				
MgO	7.13	178	Hy $MgSiO_3$	7.60	14.33	..
Na_2O	1.90	31	Hy $FeSiO_3$	6.73		
K_2O	0.58	6	Ol Mg_2SiO_4	3.36	6.62	..
P_2O_5	0.40	3	Ol Fe_2SiO_4	3.26		
H_2O+	0.76	..	Mt		3.25	..
	100.23		Ilm		5.32	..
			Ap		1.01	Σ fem 51.12
H_2O-	0.30	..				H_2O+ 0.76
						100.37

Table V. (continued).

III : 5 : 4 : 4—5 Auvergnose Or : Ab : An = 6.9 : 33.5 : 59.6.

Niggli values				Osann's system
qz	—17.0	si	103	$s_{51.9}\ a_{2.0}\ c_{5.0}\ f_{23.0}\ n_{8.4}$
al	18.5	ti	4.5	S:Al:F = 16:3:11.
fm	49.5	mg	0.48	Al:C:Alk = 11:16:3.
c	27.0	k	0.16	k = 0.9.
alk	5.0	p	0.39	

The modal composition of the rock was ascertained by a geometrical analysis, the result of which is given in Table VI. For mineral compositions see Tables I—III.

Table VI. Geometrical analysis of dolerite from Hang Mts.
Indicatrix 40 cm.

Minerals	Vol.-%	Weight-%
Plagioclase	40.2	34.2
Pyroxene	43.5	46.6
Iron ore	7.1	11.0
Secondary products (mostly chlorite after olivine) Interstitial filling	9.2	8.2

The calculation of weight percentages was based on the following sp. gravities: Plagioclase 2.7, pyroxene 3.4, iron ore 4.9, secondary products 2.8.

A comparison shows at a glance that the norm given in Table V and the modal composition as illustrated by the geometrical analysis of Table VI disagree rather markedly. Firstly, the normative felspar content surpasses the modal one by almost 50 %. Secondly, the norm shows a rather considerable olivine content, whereas in the rock this mineral is all but wanting. The numerous pseudomorphs, however, give witness of its previous existence, and thus the norm must be held to illustrate in this case the mineral relation of an earlier stage. The normative hypersthene as a matter of course combines with diopside to form pigeonite.

Starting from the data of the geometrical analysis and the composition of minerals optically ascertained, an attempt was made to recalculate the chemical analysis of Table V on mineral molecules, so as to obtain the best possible approximation to the actual mineral assemblage of the rock. The result is put down in Table VII.

Table VII. Calculated modal composition of dolerit efrom Hang Mts.

Minerals	Det.	Calc.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	P_2O_5	H_2O+
Plagioclase	34.2	34.20	18.64	..	9.87	..	..	3.79	..	1.63	..	..	..
Pyroxene	46.6	46.61	22.68	..	3.75	..	6.88	7.01	6.29	..	..	..	..
Iron ores	11.0	9.08	..	2.81	..	2,15	4.12	..	..	..	..	..	..
Apatite	—	1.00	..	..	..	..	..	0.60	..	..	..	0.40	..
Chlorite		4.13	1.44	..	..	..	1.09	..	0.84	..	..	..	0.76
Alcali felspar	8.2	5.21	2.52	..	0.77	..	..	..	..	0.27	..	..	..
Quartz		1.34	1.34	..	..	..	..	..	..	..	..	..	..
Sum	..	..	46.62	2.81	14.39	2.15	12.09	11.40	7.13	1.90	0.58	0.40	0.76

The compositions of the different minerals according to Table VII come out as follows:

Plagioclase (Weight-%) An:Ab:Or = 53.5:40.5:6 (calculated)
An: alcali felspar = 55 : 45 (optically determined)

Pyroxene (Mol.-%) $CaSiO_3$: $MgSiO_3$: $FeSiO_3$ = 33:42:25 (calculated)
$CaSiO_3$: $MgSiO_3$: $FeSiO_3$ = 35:42:23 (optically determined average).

Chlorite (Mol.-%):

$$35\,\% \,(3FeO \cdot 2\,SiO_2 \cdot 2\,H_2O) + 49\,\% \,(3MgO \cdot 2SiO_2 \cdot 2\,H_2O) + 16\,\% \,H_2O$$

Ferroantigorite Antigorite

The calculation was made under two fundamental assumptions, *viz*, firstly, that the weight percentages of plagioclase and pyroxene were satisfactorily established by the geometrical analysis, secondly, that the anorthite content of the former, as optically determined, was essentially correct. Further it was assumed that all Fe_2O_3 and FeO combine to form iron ores. Even so, the percentage of iron ores calculated falls about 2 % short of the value geometrically determined. Now it is notorious, however, that in ROSIWAL measurements one is apt to exaggerate the proportions of opaque minerals, owing to their visibility even under a thin cover of other, translucent minerals. Further the iron ores of these rocks are often intimately associated with chloritic products, and it may not always have been possible to avoid including some of that material under the same heading. As a matter of fact the proportion of chlorite and interstitial matter calculated in Table VII comes out almost 3 % higher than indicated by the geometrical record. It should also be noted that a difference of 2 % in weight percentage of the heavy iron ores corresponds to a difference of only about 1.3 % as calculated by volume.

The pyroxene composition is not entirely unambiguous, as the

distribution of $FeSiO_3$, $MgSiO_3$ and Al_2O_3 between pyroxene and chlorite is quite arbitrary. In order to ensure the best possible approximation to the pyroxene composition optically inferred, the chlorite has been calculated as alumina-free, a supposition that it in no way granted and, indeed, not very probable. Now it is well known that, in the chlorite group Al_2O_3 and Fe_2O_3 may be substituted for the group $RO \cdot SiO_2$. Consequently, it is possible in Table VII to make an interchange between pyroxene and chlorite, allotting part of the alumina to chlorite and increasing in exchange the $(Mg,Fe)SiO_3$-content of the pyroxene. By such a proceeding the composition of the chlorite becomes more plausible, but on the other side the quotient $CaSiO_3:(Mg,Fe)SiO_3$ of the pyroxene will decrease and, consequently, come to depart still more from the value optically inferred. As was already pointed out, however, (p. 15) this value probably represents a maximum one, and thus it seems hardly possible to decide definitely between the two alternatives.

In the above discussion the pyroxene composition was interpreted according to WINCHELL's diagram of 1927, which for other reasons (see p. 13) seemed the most reliable one. According to the diagram of 1935 by the same author, the $CaSiO_3$ content of the pyroxene should be only 20 % by weight—a value that is entirely incompatible with the chemical analysis. If the pyroxene is calculated with such a composition there will be a considerable amount of CaO that cannot be placed anywhere. It is not possible to allot it to plagioclase, as, firstly, the An-percentage calculated for the latter must be considered a maximum one (see p. 6) and, secondly, there is not enough silica. As there are no other minerals in the rock, that might account for this excess of CaO, it seems safe to conclude that the diagram of 1935 is not applicable for these pyroxenes.

As for TOMITA's diagram, the $CaSiO_3$-content deduced, although lower than according to WINCHELL 1927, is not so low as to be absolutely inconsistent with the chemical analysis, considering that the ROSIWAL data as well as the optical determinations are correct only within certain limits. The content of $MgSiO_3$, however, comes out so high, that the calculated MgO-percentage of the rock would surpass the actual number by more than 25 %. Consequently, this diagram, too, seems inapplicable for the present pyroxenes. Now, TOMITA's curves are based on pyroxenes poor in sesquioxydes. The discrepancy just referred to might thus be a hint, that our pyroxenes do contain alumina to an extent sufficient to influence appreciably the optical properties. As a matter of fact H. KUNO (1936) has given a revised diagram, based on $2V\gamma$ and N_β, for the determination of pigeonites rich in sesquioxydes and titania.

As a general result of the above considerations it may be said, that the $CaSiO_3$-content of these and related pyroxenes may be deduced

within reasonable limits from the optic axial angle interpreted by the diagrams of WINCHELL (1927), TOMITA, and KUNO. As for the important quotient $MgSiO_3:FeSiO_3$, however, the value c/γ seems to offer no reliable indication.

III. Plagioclase porphyrites.

Plagioclase porphyrites are represented by the following specimens:

Collection BACKLUND

1802 Liverpool Land, W. side of the northernmost of the Fame Øer. Sill in contact with limestone.
1813 As 1802.
1837 Liverpool Land, E. side of Ryders Dal. Undermost part of lava-flow.

Collection NOE-NYGAARD

322 Liverpool Land, Hurry Fjord.

Petrography.

Megascopically these rocks are distinctly porphyritic with numerous, yellowish-gray plagioclase phenocrysts scattered in a medium-grained, evengrained groundmass of grayish colour. The plagioclase crystals are generally lath-shaped, attaining a width of about 2—3 mm and a length of several cm. Occasionally tabular forms are encountered.

The microscopic investigation reveals a certain mineralogical similarity between these rocks and the olivine dolerites. In the plagioclase porphyrites, however, the mineral assemblage is strongly dominated by plagioclase, the other minerals being restricted to a ground-mass of finer grain, filling the interstices.

The plagioclase phenocrysts are only slightly zoned and, when appearing, the zoning is restricted to the peripheral parts. Carlsbad, Albite and Pericline twinning is very common, the latter being remarkably frequent. The ground-mass consists of smaller plagioclase crystals (reaching a length of 4 mm and a width of 0.5 mm), pyroxene, olivine, iron ores, chloritic material, apatite, small amounts of quartz and, possibly, a little alcali felspar.

The plagioclase laths of the groundmass, as contrary to the phenocrysts, are very frequently zoned or irregularly undulose. The zoning may be observed even in the interior parts of the crystals. Most probably this indicates a steeper temperature gradient

during the period of crystallization of the ground-mass, the equalization of chemical inhomogeneities being accordingly hampered. Recurrent zoning is occasionally observed. As in the phenocrysts Pericline twinning is remarkably frequent. In Carlsbad twins this often leads to a well-developed "herringbone structure". Sometimes these polysyntetic pericline lamellae become rather indistinct and diffuse. When combined with Albite twinning they may then form a structure that reminds of microline grating. In the large plagioclase laths the pericline lamellae are often developed only in patches and it might be questioned if this twinning is not a stress phenomenon. As a matter of fact the plagioclase has frequently been subjected to mechanical deformation resulting in micro-brecciation, translation phenomena, undulose extinction etc. The laths are traversed by crush zones and fissures, along which the twin lamellae have been displaced. The fissures are frequently cemented by pyroxene material.

The plagioclase of the ground-mass and the phenocrysts are of essentially the same composition. In both cases FEDOROW stage measurements give the average value.

$$Ab_{35}An_{65}$$

Next to plagioclase, pyroxene is the most abundant mineral. It appears in the plagioclase interstices as small grains or shreds of rather ragged outlines. Its relation to the plagioclase of the ground-mass is doleritic or, sometimes, typically sub-doleritic (KROKSTRÖM 1932b).

The pyroxene crystals very frequently exhibit traces of mechanical deformation such as, for instance, contorted planes of cleavage and a patchily undulose extinction. Their greatest diameter, as a rule, does not surpass 1 mm. It is rather probable, however, that some clusters of optically continuous small grains may represent the broken down parts of crystals originally far larger.

The optic axial angle as determined by NIKITIN's method (BEREK 1924) comes out as

$$2V\gamma = 46^\circ.5 \pm 1^\circ.$$

Consequently, the pyroxene belongs to the pigeonite series and does not differ materially, as regards $CaSiO_3$, from the pyroxene of the olivine dolerites.

Olivine appears as small rounded grains of maximum 1 mm diameter. When the mutual relations between pyroxene and olivine can be established, olivine always proves to have crystallized first. As a rule the mineral is quite fresh and unaltered. Only exceptionally a slight alteration is discernible, resulting in the formation of serpentinous

and chloritic material. The optic axial angle was determined by NIKITIN's method:

$$2V\alpha = 84°$$

indicating a fayalite percentage of 28 % (WINCHELL 1927) or 24 % (BACKLUND 1909).

The rock of the Fame Ö sill is of a slightly variable character owing to variations in the mutual proportion of plagioclase and mafic minerals. In extreme cases it may pass into almost anorthositic rocks of rather coarse grain.

Among the specimens from this sill there is also an almost black one (1802.e) showing numerous slender plagioclase laths (max. 1 cm of length) and small olivine grains (max. 1 mm) in a dense black groundmass. This specimen represents the rock of one of several narrow apophyses emanating from the main sill and intruding the quartzite of the hang wall.

Under the microscope no other phenocrysts than plagioclase and olivine could be detected, the former being by far the most abundant. As to crystallographical habit, twinning etc. they agree perfectly with the plagioclase of the coarse-grained rock and according to FEDOROW measurements they are also chemically identical, showing a composition of

$$Ab_{35}An_{65}.$$

The optic axial angle of the olivine was determined (NIKITIN's method) in two grains with the same result:

$$2\ V\alpha = 87°.$$

This value corresponds to a fayalite content of 21 % (WINCHELL) or 18 % (BACKLUND). Even for this mineral, then, the correspondence with the main rock is tolerably good.

The ground-mass is extremely fine-grained and allows of no detailed determinations of its components. It is built up, however, of divergent-radiating plagioclase laths together with ragged pyroxene shreds and possibly other mafic minerals. Further, finely disseminated iron ores are rather abundant.

From the above description as also from the geological relations it seems unquestionable that this rock represents the same material as the main sill, and owes its different character only to rapid chilling. It is rather interesting, then, to find that pyroxene is not represented among the phenocrysts, and olivine only sparsely. As for the relations olivine—plagioclase, no safe conclusions may be drawn, for as will be shown later on, there are certain indications that olivine of early deposition may have been gravitatively removed. It seems to be clear, however, firstly, that from the magma now considered, plagioclase was the

first mineral to crystallize and, secondly, that it was separating for a considerable time without being accompanied by pyroxene.

This conclusion is still more strengthened by a study of a third specimen (1808) from the same sill. It represents the immediate endogenous contact between the porphyrite sill and the quartzite. Megascopically the rock shows abundant phenocrysts of plagioclase in a dense black ground-mass.

A microscopical investigation shows that the plagioclase phenocrysts are almost idiomorphic with only slightly rounded contours. They may attain a maximum length of 4 mm. Decidedly less abundant are small grains of olivine or pseudomorphs after this mineral, now consisting of some deep green or brown material, probably of serpentinous or iddingsitic character. These phenocrysts never surpass a greatest diameter of 0.5 mm.

The plagioclase phenocrysts were optically determined in a large number of sections normal to α and normal to M and P. The results showed a very good coincidence and brought out the composition as

$$Ab_{35}An_{65}.$$

The optic axial angle of the olivine is negative but rather close to 90° and the mineral thus seems to be of essentially the same composition as the olivine of the central part of the sill.

The ground-mass is almost entirely opaque and probably represents a black glass. Only some extremely minute crystallites of felspar (?) stand out as light streaks between crossed nicols.

In order to get an idea of the mutual quantitative relations of the components, a geometrical analysis was carried out. As the plagioclase laths show a tendency of fluidal arrangement, the measurements were executed in two directions, viz. parallel to (No. 1) and at right angles to (No. 2) their main direction of elongation. Each measurement comprised an indicatrix of 30 cm and the average, entered in column 3 of table VIII below, ought to give a rather reliable idea of the composition of the rock.

Table VIII. Geometrical analysis of chilled margin of plagioclase porphyrite sill. Fame Island. — Specimen 1808.

	Vol. — %		
	1.	2.	average
Ground-mass	70.3	72.4	71.3
Plagioclase phenocrysts	27.2	24.4	25.8
Olivine phenocrysts	1.4	1.2	1.3
Olivine pseudomorphs	1.1	2.0	1.6

The spec. gravity was determined by weighing in air and in water.

$$G\frac{18^\circ}{4^\circ} = 2.948.$$

Assuming the specific gravities of the identifiable components to be: plagioclase 2.7, olivine 3.5, pseudomorphs 3.0, the specific gravity of the ground-mass comes out as

$$G = 3.027$$

Consequently the composition of the rock by weight percentage should be

Ground-mass	73.2
Plagioclase	23.6
Olivine + pseudomorphs	3.2
	100.0

Even in this case, then, there is strong evidence of a rather long period during which plagioclase was the only mineral precipitated.

In the immediate vicinity of the vertical dike represented by specimen 1838, (p. 4), there appears a basaltic lava-flow, from the undermost chilled margin of which specimen 1837 was collected. This rock shows, megascopically, abundant grayish or brownish phenocrysts in a dark ground-mass. Under the microscope the porphyritic texture is still more conspicous. The phenocrysts consist of plagioclase (1—4 mm of size) and far less numerous, small (max. 0.5 mm) grains of serpentinous material, which by their outlines appear to represent original olivine. The plagioclase crystals are sub-idiomorphic, showing smoothly rounded contours and small embayments that appear to result from corrosion. Zoning is not very conspicuous and only in a few cases discontinuous. Generally only a slightly undulose extinction is observed.

The slide is traversed by an irregular vein, about 0.1 mm wide, dissecting both phenocrysts and ground-mass and filled by calcite.

The ground-mass is extremely fine-grained and its minerals cannot be exactly identified. It appears, however, that felspar is the most abundant component, forming irregular laths. Further, there are observed ragged portions of medium birefringence, probably representing pyroxene or its secondary products. All over the matrix iron-ores are scattered as extremely abundant small lumps or rods.

The result of a geometrical analysis is given in Table IX.

Table IX. Geometrical analysis of chilled bottom of basaltic lava-flow. E. of Ryders Dal, Liverpool Land.—Specimen 1837.

	Vol.-%	Weight-%
Ground-mass	70	71.7
Plagioclase phenocrysts	28	26.2
Serpentinous phenocrysts	2	2.1
	100.0	100.0

The specific gravity of the rock was determined by weighing in water and in air:

$$G \frac{18^\circ}{4^\circ} = 2.879.$$

Assuming the specific gravity of the plagioclase to be 2.7 and that of the serpentinous matter 3.0, the corresponding value for the ground-mass comes out as

$$G = 2.95.$$

from which data the weight percentages of table IX were calculated.

The composition of the plagioclase phenocrysts was determined by FEDOROW measurements:

$$Ab_{35}An_{65}$$

It is evident that even in this case the conclusion gathered from specimens 1802e and 1808 holds good, *viz.* that crystallization was initiated by plagioclase which, possibly with exception for olivine was for a long time the only mineral deposited. A comparison of the two analyses of tables VIII and IX, furthermore, brings out the rather surprising fact that the mutual proportions of plagioclase phenocrysts, olivine phenocrysts (or pseudomorphs) and ground-mass are all but identical in the two rocks. This seems to indicate not only that the two rocks, although occurring at different localities and in different geological setting—sill and flow respectively—were generated by the same magma, but also that in both cases the erupting magma had reached the same stage of intercrustal crystallization. Now it is perfectly possible that this stage may have represented an equilibrium maintained for rather a long time within the magma-chamber but, nevertheless, the fact just referred to seems to give a hint that both rocks are essentially contemporaneous.

Genetical discussion.

A chemical analysis of specimen 1837 is given in Table X below. Considering the above deductions, it seems reasonable to assume that this analysis is rather representative for the plagioclase porphyrites of this region in general.

The close geological association of the olivine dolerite (specimen 1838) and the plagioclase porphyrite (specimen 1837) raises the interesting question whether or not the olivine dolerites and the plagioclase porphyrites of this region are genetically connected. Unfortunately no analysis of the rock 1838 is available but the microscopic investigation shows that, mineralogically and texturally, it is almost identical

Table X. Analysis 2. Plagioclase porphyrite from chilled bottom of lava flow. Liverpool Land, E of Ryder's Dal. Coll. BACKLUND no. 1837.

Sp. gr. $\frac{18^\circ}{4^\circ} = 2.879$ Analyst: N. SAHLBOM.

	Weight-%	Mol. prop.	Norm			
SiO_2	48.00	800	Qu		4.86	..
TiO_2	6.59	83	Or		5.00	..
Al_2O_3	12.65	124	Ab		20.96	..
Fe_2O_3	1.91	12	An		20.85	Σ sal 51.67
FeO	8.47	118				
MnO	0.21	3	Di	$CaSiO_3$ ... 14.50		
CaO	12.17	217		$MgSiO_3$ ... 10.10	27.77	..
MgO	4.94	124		$FeSiO_3$ ... 3.17		
Na_2O	2.51	40	Hy	$MgSiO_3$ ... 2.30	2.56	
K_2O	0.79	9		$FeSiO_3$ ... 0.26		..
P_2O_5	0.68	5	Ilm		12.62	..
H_2O+	1.06	..	Mt		2.78	..
	99.98		Ap		1.68	Σ fem 47.41
H_2O-	0.54	..				H_2O+ 1.06
						100.14

III: 5:4:4—5 — Auvergnose Or : Ab : An = 10.7:44.8:44.5.

NIGGLI values			
qz	— 6.6	si	121.4
al	19	ti	12.6
fm	41	mg	0.46
c	33	k	0.18
alk	7	p	0.76

OSANN's system
$s_{57.85}$ $a_{3.0}$ $c_{4.0}$ $f_{23.0}$ $n_{8.1}$
S : Al : F = 18:2.5:9.5.
Al : C : Alk = 9.5:16.5:4.0.
k = 1.04.

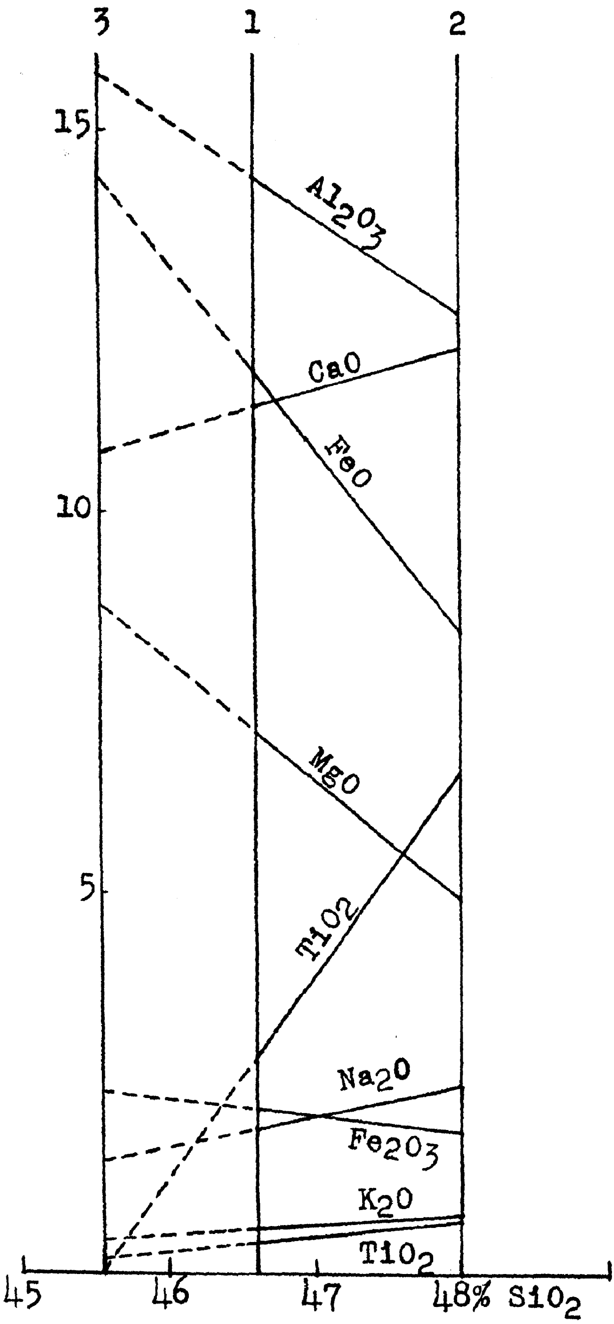


Fig. 3. Addition—subtraction diagram for the olivine dolerite, analysis 1, and the plagioclase porphyrite, analysis 2. The most basic composition of the material that may be assumed to have been removed is indicated by the ordinate 3.

with the dolerite of analysis 1 on p. 18. It seems rather safe to conclude, therefore, that its chemical composition does not fall far from this analysis and a comparison of tables V and X is consequently of some interest. To facilitate such a comparison the two analyses have been plotted in a diagram (fig. 3).

It is true that both analyses fall within the same sub-rang of the C. I. P. W. classification—Auvergnose—but it is a well-known fact that this sub-rang is a fairly large one and includes rocks of rather different character. As a matter of fact the norms as well as the NIGGLI values differ rather markedly. Thus the dolerite shows a considerable amount of normative olivine whereas the porphyrite norm contains about 5 % quartz. The mutual proportions of CaO and (Fe, Mg, Mn)O also come out rather different, the quotient c:fm being 0.55 in the dolerite against 0.80 in the porphyrite. Finally the content of TiO_2 is about 2 ½ times as high in the porphyrite as in the dolerite whereas alumina is nearly 2 % lower.

Now the fine-grained implication texture of the dolerite analyzed seems to preclude the possibility, that it might have attained its present composition as a result of crystal accumulation. According to the hypothesis of crystallization differentiation it ought therefore to represent a stage on the "liquid line of descent". Consequently, if the two rocks belong to the same differentiation suite we should be able to arrive at the composition of the porphyrite by deducting from the dolerite a mineral assemblage that may reasonably be assumed to represent the earliest phase of deposition of that particular magma when allowed to cool slowly.

To find such a mineral assemblage we have to resort to fig. 3. Here any composition will do that is represented by the intersections of the extenuations (broken lines) of the oxide lines and an ordinate to the left of that of the dolerite. A limit is set by the point where the TiO_2 line reaches the abscissa. As this very point is the most favourable as regards the quantity of material removed, a calculation was made starting from a composition corresponding to $SiO_2 = 45.59$. One finds that in order to arrive at the porphyrite composition no less than 57.36 % of the dolerite magma must be removed by crystallization, the composition of the material deducted being given in table XI below.

As is easily seen, there is nothing very remarkable in the composition of the material that would have to be deposited in the early stages of crystallization of the dolerite magma. On the contrary the norm shows it to consist of about 55 % of plagioclase $Or_4Ab_{23}An_{73}$ and for the rest mainly olivine and pigeonitic pyroxene. The only suspicious fact is the rather high fayalite content of the olivine which is not at all in accordance with the data actually determined in the olivine dolerites.

Table XI. Composition of material to be removed from the dolerite magma (analysis 1) in order to give the porphyrite composition (analysis 2).

	Weight-%	Mol. prop.	Norm			
SiO_2	45.59	760	Or		2.22	..
Al_2O_3	15.68	154	Ab		12.58	..
Fe_2O_3	2.33	14	An		40.03	Σ sal 54.83
FeO	14.63	203				
CaO	10.83	193	Di	$CaSiO_3$ ... 7.42		
MgO	8.76	219		$MgSiO_3$ ... 3.40	14.78	..
Na_2O	1.45	24		$FeSiO_3$ ... 3.96		
K_2O	0.42	4	Hy	$MgSiO_3$ ... 3.80	8.82	..
P_2O_5	0.19	1		$FeSiO_3$ ... 5.02		
	99.88		Ol	Mg_2SiO_4 .. 10.01	18.48	..
				Fe_2SiO_4 ... 8.47		
			Mt		3.25	..
			Ap		0.34	Σ fem 45.67
						100.50

There is another point, however, that seems to preclude definitely that the mutual relations of the two rocks should be governed simply by crystal fractioning. We have found that at the stage when the rest magma should have reached the composition of the porphyrite, no less than 57 % of the original magma should have crystallized, yielding 42 % × 57 % = 24 % of olivine and pyroxene. It must certainly be considered impossible that the porphyrite magma, if generated in such a way, should deposit in the first stages of further crystallization practically nothing but plagioclase, and a rather basic plagioclase at that. The analysis proves irrefutably that the chemical possibilities of pyroxene formation are by no means exhausted.

It remains, then, the possibility that the plagioclase phenocrysts of the porphyrite are not authigenous but a result of enrichment by crystal sorting. This assumption seems rather far-fetched as the relatively light plagioclase crystals hardly would be expected to gather towards the bottom of the lava flow. There is always the possibility, however, that an enrichment within the upper parts of the magma chamber has taken place, in which case the rapid cooling at the bottom of the flow may have fixed the phenocrysts in their present position. For sake of completeness, then, even this possibility has to be investigated.

Now, there can be no doubt whatsoever, that the very dense ground-mass of the porphyrite must have represented a true melt. Therefore a comparison of this ground-mass and the fine-grained dolerite is not

subject to the possible objections just raised. Starting from the geometrical analysis table IX and the chemical analysis table X, we may calculate the approximate composition of the ground-mass, which is given in table XII. The composition of the plagioclase phenocrysts was taken as $Or_5Ab_{30}An_{65}$, and the very small quantity of serpentinous phenocrysts was neglected. This omission does not effect the result to any appreciable extent.

As before, the assumption is made that the material detracted was Ti-free, as this assumption involves the smallest possible amount of fractioning. We find, that in order to obtain the composition of the porphyrite ground-mass no less than 69 % of the dolerite magma has to crystallize. The normative composition of the material thus removed is given in Table XIII and presents nothing abnormal. If, starting from 321 parts of dolerite magma, there are removed 152 parts of plagioclase ($Or_5Ab_{26}An_{69}$), 45 parts of pyroxene, 40 parts of olivine (Fa_{55}) and 8 parts of iron ores + apatite, the remainder will be 74 parts of the composition of the porphyrite ground-mass.

Now the plagioclase phenocrysts actually present in the rock may or may not represent a portion of those 152 parts that would have had to crystallize from the dolerite magma. The former alternative would necessitate a mineral fractioning that is rather difficult to conceive. Out of a crystallized portion corresponding to about 77 % of the original

Table XII. Composition of the ground-mass of the porphyrite of table X as obtained by the deduction of 26.2 % of plagioclase ($Or_5Ab_{30}An_{65}$).

	Weight-%	Mol. prop.	Norm			
SiO_2	47.30	788	Qu		6.60	..
TiO_2	9.06	114	Or		5.00	..
Al_2O_3	6.37	63	Ab		17.82	..
Fe_2O_3	2.63	16	An		5.56	Σ sal 34.98
FeO	11.65	162				
MnO	0.29	4	Di	$CaSiO_3$ ... 20.18		
CaO	12.02	214		$MgSiO_3$ ... 14.40	38.54	..
MgO	6.79	170		$FeSiO_3$ ... 3.96		
Na_2O	2.17	34	Hy	$MgSiO_3$ ... 2.60	3.39	..
K_2O	0.78	9		$FeSiO_3$ ... 0.79		
P_2O_5	0.94	6	Ilm		17.33	..
	100.00		Mt		3.71	..
			Ap		2.02	Σ fem 64.99
						99.97

IV: 2:1:2:3 — No name.

Table XIII. Composition of material to be removed from the dolerite magma (analysis 1) in order to give the composition of the porphyrite ground-mass (Table XII)

	Weight-%	Mol. prop.	Norm			
SiO_2	46.67	778	Or		2.78	ε sal 57.73
Al_2O_3	18.14	177	Ab		15,20	..
Fe_2O_3	1.95	13	An		39.75	..
FeO	12.04	167	Di	$CaSiO_3$ ... 6.26		
MgO	7.34	184		$MgSiO_3$ ... 2.90	12.46	..
MnO	0.22	3		$FeSiO_3$ ... 3.30		
CaO	11.20	200	Hy	$MgSiO_3$ ... 3.90		
Na_2O	1.79	29		$FeSiO_3$ ... 4.36	8.26	..
K_2O	0.49	5	Ol	Mg_2SiO_4 .. 8.12		
P_2O_5	0.16	1		Fr_2SiO_4 ... 10.10	18.22	..
	100.00		Mt		3.02	..
			Ap		0.34	ε fem 42.30
						100.03

melt, the mafic minerals would have had to disappear all but quantitatively whereas about 15 % of the plagioclase should have escaped removal. What reason, then, could have induced those 15 % to remain in a milieu, from which 85 % of the same mineral most eagerly managed to escape? Certainly it cannot have been the growing viscosity of the melt—the dimensions of the plagioclase phenocrysts bear witness that they have been growing during a considerable part of the period of crystallization. The other alternative would imply, firstly, a complete removal of the solid material yielded by the crystallization of $\frac{247}{321}$ (= 77 %) of the dolerite melt and, secondly, a subsequent enrichment of the residual liquid in plagio-clase of about the same composition as that earlier removed. If anyone should care to take up this line of reasoning, it would certainly be rather difficult to prove him wrong. It seems to me, however, that such a far-fetched explanation may be disregarded.

It would appear then that the melts responsible for the formation of the olivine dolerite and the plagioclase porphyrite cannot possibly have belonged to the same liquid line of descent. This conclusion furnishes supplementary evidence in favour of the conception of a different geological age of these rocks, as already inferred from geological data.

The porphyrite specimen 1837 is of no little interest from a theoretical point of view, inasmuch as the composition of its ground-mass can be calculated fairly accurately (table XII on p. 32). There seems

to be no doubt that this ground-mass once represented an actual melt. As for the bulk composition of the rock such a conclusion is not a priori permissible, and it seems worth while to discuss a little further some problems that present themselves in this connection.

A few years ago BARTH (1936) attemped to locate as closely as possible the position within the tetrahedron ab — an — di — hy (normative values) of the boundary surface separating basaltic magmas of early plagioclase crystallization from those of early pyroxene crystallization. Recalculating the normative values ab, an, di and hy on a sum of 100 he found from empirical data that this surface was determined by the equation $f\,(\text{norm}) = ab' + 2\,di' + 2.3\,hy' = 123$. Thus rocks with $f\,(\text{norm}) < 123$ should be expected to yield plagioclase as the first product of crystallization, whereas in rocks with f (norm) > 123, pyroxene would be the first mineral to separate. Except for some minor objections, which will be returned to later, there seems to be no doubt as to the validity of this very important and interesting conclusion.

Now, if the present rock is put to the test of BARTH's equation it is found that f (norm) is 114.3, which would thus indicate that from a melt of this composition plagioclase would be the first mineral to crystallize. We may even go a step further, inasmuch as the equation in question allows us to calculate the amount of plagioclase that will separate, before the boundary surface is reached, and the crystallization of pyroxene will begin.

As such a calculation is of great general interest, it seems worth while to deduce the general formula. For that purpose the following terms may be introduced.

k = the quotient an:ab of the plagioclase deposited

ab', an', di', hy' = the original normative values recalculated on a sum of 100.

$ab'_x, an'_x, di'_x, hy'_x$ = the normative values of the melt (recalculated as before) after a certain amount, x weight-%, of plagioclase has been deposited.

$f = ab' + 2\,di' + 2.3\,hy'$ (BARTH's function)

$f^x = ab'_x + 2\,di'_x + 2.3\,hy'_x$

If we put $y = \dfrac{100\,\dfrac{x}{1+k}}{ab + an + di + hy}$ we find generally:

$$\left.\begin{aligned} ab'_x &= \frac{(ab'-y)\,100}{100-y(1+k)} \\ di'_x &= \frac{di'\cdot 100}{100-y(1+k)} \\ hy'_x &= \frac{hy'\cdot 100}{100-y(1+k)} \end{aligned}\right\} \quad f^x = \frac{ab'-y+2di'+2{,}3hy'}{\frac{1}{100}\left[100-y\,(1+k)\right]} = \frac{f-y}{1-\frac{y}{100}\cdot(1+k)},$$

This leads to

$$y = \frac{100\,(f^x-f)}{f^x(1+k)-100}$$

and, by substitution:

$$x = \frac{(f^x-f)\,(ab+an+di+hy)}{f^x-\frac{100}{1+k}}$$

Now, according to Barth, the boundary surface is characterized by $f^x = 123$. Further ab + an + di + hy of the present rock is 72,14, f is 114,3 and the equation takes on the following form:

$$x = \frac{8{,}7\cdot 72{,}14}{123-\frac{100}{1+k}} = \frac{627{,}6}{123-\frac{100}{1+k}}.$$

In fig. 4 part of the hyperbola, representing this equation for the rock now in question, has been constructed, the composition of the plagioclase, however, being represented by percentages instead of by the quotient an:ab. Assuming the plagioclase deposited to have the composition $ab_{40}an_{60}$, we find that the crystallization of 7.5 % of plagioclase would be quite sufficient to bring the melt to a position on the boundary surface. Even allowing for a far less calcic composition, say $ab_{60}an_{40}$, the corresponding amount would be only about 10 %. Now the geometrical analysis shows about 26 % of plagioclase phenocrysts. According to the calculation just presented more than one half of these phenocrysts should have been precipitated at a time during which the composition of the melt was changing along the boundary surface. Consequently, a generous amount of mafic minerals, olivine and/or pyroxene, would have had to separate along with the plagioclase. Quite contrarily, the actual mineral assemblage includes only a very insignificant quantity of olivine pseudomorphs.

There seem to be only two possible explanations to this puzzling inconsistency. Either all of the plagioclase was originally generated elsewhere and was subsequently accumulated in its present milieu,

presumably by gravitational rising. Or there has been effected an all but quantitative removal of the mafic minerals that were deposited during the later part of the period of intracrustal crystallization. It is rather difficult to decide between these alternatives, but it would seem that the last one is perhaps the most probable one. Firstly, the sp. gravity of a melt corresponding to specimen 1837 would not probably

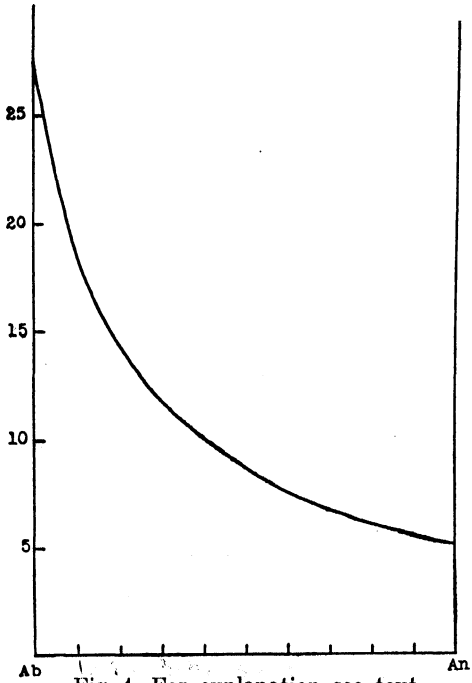


Fig. 4. For explanation see text.

have been much higher than 2.7 (= about 6.5 %) less than the solid rock), that is about the same value as for $Ab_{40}An_{60}$. Even if a difference may actually have existed, it was most probably rather insignificant and it seems very doubtful whether it might have effected gravitational transport to any notable extent. Secondly, the rather close correspondence between the rocks 1808 (table VIII on p. 25) and 1837, as regards their phenocryst percentages, may perhaps be taken as a hint that the plagioclase phenocrysts are authigenous in their present milieu. However, one cannot entirely discard the possibility that this correspondence may be purely coincidental.

Even the second assumption, however, *viz.* that the mafic minerals have been gravitatively removed, encounters some difficulties. The principal one pertains to the composition of the ground-mass, as calculated in table XII on p. 32. If the value $f = ab' + 2\,di' + 2.3\,hy'$ is calculated, it comes out as 157, a rather extreme value that would

indicate a position within the pyroxene field at a considerable distance from the boundary surface. It is rather difficult to picture by what means the melt, after having reached the two-mineral surface and followed it for some time, could again be brought to depart from it and reach a position far within the pyroxene field. It would seem, that this objection is sufficiently serious at once to invalidate the explanation attempted. Further consideration, however, shows that this is not necessarily the case. As BARTH has stressed (*op. cit.* p. 333) the actual boundary surface cannot be expected to coincide exactly over its whole area with the plane determined by BARTH's equation. The latter is valid only in the part of the tetrahedron that corresponds to typically basaltic liquids. Yet, it seems at first surprising that in this very part of the tetrahedron, rather close to the ternary surface Ab — An — Di (ab = 27.5, an = 8.5, di = 59, hy = 5) there should be such a marked discrepancy between the boundary surface and the ternary boundary curve, as constructed by BOWEN (1915). Actually, however, no such peculiar departure is by necessity indicated. We must bear in mind that the position of the surface, as depicted by BARTH, refers to normative values. This is certainly justified for typically basaltic rocks, which according to experience do not show too marked differences between norm and mode. For the ground-mass calculated in table XII this, however, most probably does not hold good. A melt of such a composition would most certainly upon slow cooling form a mineral assemblage quite different from the normative one. So for instance would a great part of the components of the extremely high normative ilmenite most assuredly enter into pyroxene. At any rate, it seems rather safe to conlude that in such a case the norm is of little or no value for locating the boundary surface. In other words, it is probable that within the normative tetrahedron, this surface can be even approximately defined only in those parts and for those rocks, that show no too great discrepancy between norm and mode.

Moreover, this last hypothesis is capable of explaining a rather peculiar trait of the analysis, table X, *viz.* the low MgO content— 4.94 %—which can scarcely be considered a characteristic of the basalts of East Greenland. So for instance an average of seven basalts from this region (BACKLUND and MALMQVIST 1932 p. 47) shows MgO = 7.52, that is a number more than 50 % higher than that of the present rock. Even WASHINGTON's average of Thulean basalts (WASHINGTON 1922 p. 789) attains 6.79 %. Now, if some amount of early olivine is supposed to have been removed, this incompatibility is easily accounted for. Indeed, if 8 % of olivine of the composition $Fo_{70}Fa_{30}$ is added to the plagioclase porphyrite, the composition comes out as shown by column I of table XIV below. In this table, for comparison, there are

Table XIV.

	I	II	III
SiO_2	47.08	46.28	47.46
TiO_2	6.07	3.26	2.71
Al_2O_3	11.66	11.95	13.89
Fe_2O_3	1.76	4.81	3.58
FeO	9.37	8.28	9.38
MnO	0.19	0.19	0.22
MgO	7.50	7.52	6.79
CaO	11.21	11.69	9.83
Na_2O	2.31	2.28	2.90
K_2O	0.73	0.92	1.01
P_2O_5	0.63	0.45	0.43
H_2O^+	1.47	2.30	1.48
	99.98	99.93	99.68

I Hypothetical magma which would yield after the removal of 7.5 % of olivine, $Fo_{70}Fa_{30}$, the composition of specimen 1837 above.
II East Greenland basalts, 7 analyses.
III WASHINGTON's Thulean basalts, 33 analyses.

furthermore listed the above-mentioned averages of East Greenland (column II) and Thulean (column III) basalts.

Compairing columns I and II we find, except for TiO_2 and the iron oxides, all but perfect agreement. As for the latter the discrepancy is largely a matter of a different degree of oxidation, the total iron being much the same, vis. 11.0 in column I as against 12.6 in column II (calculated as FeO). The high TiO_2 content on the other side, as far as experience goes, is common to almost all Greenlandic basaltic rocks (Cf. BACKLUND and MALMQVIST *op. cit.*, WASHINGTON, *op. cit.* and HOLMES 1918), although the present value seems to be the highest one yet recorded. If rather high on an average, titanium, however, even in this region varies within rather wide limits, and the extreme value presented by specimen 1837 must not, therefore, be put too much weight to. Most probably the titanium content of the Greenlandic basalts does not depict more or less local variations but is a feature connected with the magmatic evolution in the region as a whole. A more detailed discussion of this problem would necessitate a far more abundant analytical material than is by now available. It might be worth while, however, to recall that a similar concentration of TiO_2 is displayed on a smaller scale by the Jotnian Hällefors dolerite in Middle Sweden (KROKSTRÖM 1936). In that case the explanation seems to be that ilmenite of early crystallization was removed by gravitation from the

upper parts of a magma basin and was subsequently remelted at lower levels.

As in the above discussion the equation proposed by BARTH has played an important rôle, it seems only proper to devote some attention to the question of its general applicability. As long as saturated or only slightly undersaturated rocks are concerned, there seems hardly to be any serious objections to its validity. For rocks with high normative olivine, however, its usefulness may reasonably be considered somewhat doubtful. Certainly an essential amount of FeO and MgO contained in normative olivine must have some influence on the course of crystallization and yet this influence is in no way allowed for in the equation. BARTH himself states that "the boundary surface - - - - - - in part must represent the boundary between plagioclase and the early olivine crystals that in later stages *were completely converted to pyroxene*" (loc. cit. p. 330, italics by me). It seems rather obvious, then, that only saturated magmas were taken into consideration, for in highly undersaturated ones, olivine will certainly not be completely converted to pyroxene. This slight objection is only put forth in order that BARTH's rather ingenious deductions should not run the danger of being uncritically applied.

Aphanitic veins.

Before leaving the plagioclase porphyrite a short description should be given of a rather peculiar rock occurring as apophyses in the porphyrite. The rock is black and to the naked eye it is completely aphanitic. Specimen 1813 of BACKLUND's collection shows the rock as a narrow vein within the porphyrite. The two rocks are separated by a grayish zone of distinct, although very fine grain.

Under the microscope the apophysis is found to consist of an all but opaque matrix, probably representing an iron-rich glass. In this matrix there are scattered numerous small fragments of plagioclase laths and of plagioclase-pyroxene aggregates. The fragments give the impression of having been torn off the fine-grained zone immediately adjoining the aphanitic apophysis.

This fine-grained rock is built up in a rather intricate fashion. Most conspicuous are numerous plagioclase grains, lath-shaped or more or less isometric. They show idiomorphic tendencies and stand out from their environment by their higher birefringence and refraction, by their freshness and by being as a rule rather intensely twinned. Because of their small dimensions (the greatest diameter nowhere surpassing 0.1 mm) no exact optical determinations were possible, but it may be stated that 2 V is fairly close to 90° and the refraction distinctly higher than of Canada balsam. Consequently, there seems to be nothing

speaking against their composition being the same as that of the plagioclase of the porphyrite proper. An oligoclase composition is, however, also possible although perhaps less probable.—Without nicols these plagioclase grains stand out as white patches against the rest of the mineral mass, which is coloured a dirty green by abundant chloritic material.

This matrix consists of felspar, pyroxene—partly intensively chloritized—and rather abundant iron-ores. The texture is allotriomorphic-granular. Optical determinations of the minerals could not be executed but is seems most probable that the felspar—which differs distinctly from the above-mentioned plagioclase—is orthoclase. Apatite is rather conspicuous, appearing as numerous slender needles both in the more distinct felspar grains and in the matrix felspar. The fine-grained zone shows sharp boundaries against the dense apophyse and is further observed as inclusions within the latter. Possibly these "inclusions" are, however, only apparent, and may by caused by the section cutting obliquely the irregular boundary between the two components.

The boundary relations between the fine-grained zone and the main rock are much more intricate. In the immediate vicinity of the fine-grained zone the large plagioclase laths are often surrounded by a narrow stripe of lower anorthite content, the boundary against the main crystal being marked by a distinct BECKE line. This contact line obviously follows the rather well-developed idiomorphic contours of the central plagioclase, whereas the outer contour of the crystal is quite irregular. Another conspicuous feature is the appearance within this outer rim of numerous apatite needles exactly analogous to those just mentioned above. These observations seem to establish beyond doubt that the outer rim is a product of later growth and not a result of albitization. As a matter of fact the slightly reddish tinge of this rim makes it probable that it consists of orthoclase, though no definite proofs could be gained in this respect.

Another interesting observation is that, occasionally, plagioclase laths belonging to the porphyrite are veined and brecciated by the fine-grained material. When this brecciation is especially intense, a picture results that differs from that of the typical gray zone only by the larger dimensions and greater abundance of the plagioclase laths.

One is rather forced to the conclusion that the fine-grained material has been derived from the plagioclase porphyrite by a combination of crushing and refusion. The close association with the dense apophysis seems to allow af no other explanation than that the magma, from which the latter was formed, was also responsible for these processes of alteration.

IV. Basalts.

Under this heading I have classed a number of rocks of black or almost black colour and extremely fine grain. To the naked eye most of them are completely aphanitic but a few specimens of distinct although very fine grain form transitional links to the dolerites previously described. Some of these rocks are identical with the types called plagioclase basalts by MALMQVIST (BACKLUND and MALMQVIST 1932) but they do not all fulfill the condition of being distinctly porphyritic.

The following specimens were examined:

Collection BACKLUND—LUPANDER

I:110	Basalt	from	dike, Scoresby Sund, Röde Ö.
IV: 38	,,	,,	central part of E-W dike, S. part of Röde Ö.
IV: 39	,,	,,	marginal — — — —
Mc 86	,,	,,	dike, Flyver fjord
Mc 88	,,	,,	,, ,,
Mc 89	,,	,,	,, ,,
Mc 90	,,	,,	,, ,,

Collection WENK

167 Basalt from dike. Strike E-W, dip vertical, width 15 m, Scoresby Sound, S. part of Röde Ö.

Collection ROSENKRANTZ

3	Basalt	from	central part of sill, Jameson Land, Moskusokseklöft
4	"	"	marginal — — — — —
7	"	"	dike, Jameson Land, N. part of Nathorsts Fjæld (Hang Mts).

Even microscopically these rocks are all very much alike, the slight differences being gradual and probably due to different rate of cooling. The main mineral constituents are in order of abundance: plagioclase, pyroxene, iron ores and olivine, the last named mineral only as rather sparse small grains. The plagioclase shows an average composition $Ab_{35}An_{65}$ and forms minute divergent-radiating laths of markedly irregular outer boundaries. Their length in most specimens does not exceed 0.2 mm. Pyroxene, of the same average composition as that of the dolerites, forms more or less xenomorphic small grains between

the plagioclase laths. The larger of these pyroxene grains, however, enclose ophitically part or the whole of small plagioclase laths which latter are seen to wedge out rapidly towards the centre of the pyroxene. The structure, consequently, is intermediate between sub-ophitic and doleritic. The iron ores invariably form the last filling in the interstices. Olivine is very sparse.

Table XV. Analysis 3.
Basalt from dike, Röde Ö, Coll. LUPANDER I:110.
$\text{Sp. gr.} \frac{14^\circ}{4^\circ} = 3.067.$

	Weight-%	Mol. prop.	Norm			
SiO_2	47.94	777	Or		3.34	..
TiO_2	3.06	35	Ab		16.77	..
Al_2O_3	12.53	141	An		23.63	Σ sal 43.74
Fe_2O_3	3.15	14				
FeO	11.00	165	Di	$CaSiO_3$ ... 14.38		
MnO	0.27	3		$MgSiO_3$ ... 8.00	28.19	..
CaO	12.05	204		$FeSiO_3$ ... 5.81		
MgO	7.11	178	Hy	$MgSiO_3$ ... 9.80	17.19	..
Na_2O	1.95	31		$FeSiO_3$ ... 7.39		
K_2O	0.60	6	Mt		4.64	..
P_2O_5	0.24	3	Ilm		5.93	..
H_2O+	0.31		Ap		0.57	Σ fem 56.48
	100.21					100.26
H_2O-	0.47					

III: 5 : 4 : 4—5 *Auvergnose* Or : Ab : An = 7.6 : 38.3 : 54.1.

NIGGLI values				OSANN's system
qz	—13.5	si	106.5	$s_{53.1}\ a_{2.0}\ c_{4.0}\ f_{24.0}\ n_{8.4}$
al	16.5	ti	5.2	S : Al : F = 16 : 2 : 12
fm	50.0	mg	0.13	Al : C : Alk = 10 : 17 : 3
c	28.5	k	0.16	k = 0.85
alk	5.0	p	0.47	

A couple of specimens (Mc 89 and 90) show a somewhat coarser grain, the plagioclase laths exhibiting more clean-cut boundaries. These rocks have been classed as basalts only because of their indubitable genetic connection with the fine-grained types. As a matter of fact they could as well have been classed among the olivine dolerites and the existence of such transitional types seems to prove without doubt the petrological identity of the dolerites and basalts of this region.

Their different development must be considered as due largely to different conditions of cooling.

This conclusion is supported, furthermore, by the analysis of table XV which shows a rather good agreement with the dolerite analysis of table V (p. 18).

V. Anorthoclase rock of Hurry Fjord.

Among the specimens from Liverpool Land there is one (Coll. Backlund 1767 and 1770) from a vertical dike at the eastern shore of Hurry Fjord, S. S. E. of the Fame Öer. The dike strikes N40°E. and its wall rock is granite. The dike rock is markedly different from those previously described, and its field relations seem to suggest that it represents an apophysis from a larger dike of lamprophyric composition which crops out in the immediate vicinity. The microscopic examination confirms this conclusion. Such lamprophyric rocks have been observed at several localities in this district and were discussed already by Nordenskjöld (1909 p. 208). Several specimens of them are included in the collections now under investigation. It is rather uncertain, however, when the author may find opportunity to give a more detailed description of this very interesting rock series. For this reason it seems convenient to give here a separate account of the rock specimen 1767, as it presents some features of very great interest.

To the naked eye the rock shows an extremely fine grain and is of a slightly brownish gray colour. Among the mineral components only numerous small biotite scales can be discerned megascopically. Within this fine-grained matrix there are furthermore observed a number of more or less irregularly rounded light-coloured patches that may occasionally attain a diameter of 5 mm but are as a rule far smaller. At a superficial glance they may be mistaken for amygdale fillings but a closer examination reveals that they are most probably more intimately connected with the main rock, a conclusion that is also confirmed by the microscopic investigation.

Under the microscope the rock is found to consist of anorthoclase, biotite, pyroxene (+ chloritic and serpentinous secondary products), calcite, iron ores, apatite and a few grains of titanite.

Anorthoclase is the dominant mineral component and forms sort of a matrix, all over which the other minerals are scattered. Its separate individuals attain a maximum diameter of 0.5 mm and show some tendency of lath-shaped development. The boundaries between adjacent

grains are, however, rather indistinct. In between these larger crystals there are also portions of entirely allotriomorphic grains or extremely small crystallites of the same mineral. It seems by no means improbable that the felspar mass was once entirely or almost entirely a glass. Optical determinations of the felspar are greatly hampered by the fine grain, the low birefringence and the generally rather indistinct twinning. By resorting to specially thick slides (50—60 μ) it was, however, possible to obtain fairly satisfying optical data. Thus the optic axial angle was determined on the FEDOROW stage in five individuals, three different methods being used. The results were $2V\alpha = 42°, 45°, 42°, 41°, 43°$, giving as an average

$$2V\alpha = 43°$$

The refractive indices are all lower than that of Canada balsam, the dispersion $\varrho > v$ around α is rather distinct. Only simple twins are encountered, usually according to the Carlsbad law but the Baveno law is also fairly well represented. A complete FEDOROW-stage measurement shows the felspar to be distinctly triclinic. Some individuals show a slight anti-perthite structure. All these data go to show that the mineral belongs to the anorthoclase group. Owing to our limited knowledge of the optical variations within this group it seems to be impossible, so far, to deduce its composition more definitely. Biotite is rather abundant as small scales scattered all over the felspar matrix. Their maximum diameter is 0.2 mm and the mineral is uniaxial with strong pleochroism:

α = colourless to pale straw-yellow
β = yellowish brown
γ = chestnut brown

Pyroxene is present only as rather insignificant relics but originally it seems to have been more abundant, as witnessed by the great amount of chloritic and serpentinous secondary products. These secondary aggregates in most cases still reveal the distinct crystallographic boundaries of an earlier pyroxene phenocryst, and it seems probable that at least most of this mineral was originally present as phenocrysts. The following optical determinations were made:

$2V\gamma = 55°$

$$\left.\begin{array}{r} N\gamma - N\alpha = 0.024 \\ N\beta - N\alpha = 0.005 \end{array}\right\}$$ The thickness of the slides was obtained by measuring the relative retardation in anorthoclase, assuming $N\gamma - N\alpha$ of the latter to be 0.006.

$c/\gamma = 36°$

The mineral is colourless and non-pleochroic.—The optical data correspond exactly to those of a pyroxene used by WINCHELL in constructing his determinative diagram for the series diopside-clinoenstatite. According to this diagram, then, its composition should be 75 % diopside + 25 % clinoenstatite.

Calcite is rather abundant. Partly it is distributed all over the rock in small, irregularly scaly aggregates, partly it builds up sector-shaped aggregates of larger crystals.

Iron ores are abundantly distributed all over the matrix as small grains of an average diameter of 0.1 mm. The grains sometimes have irregularly ragged outlines but most frequently they show clean-cut quadratic sections.

Apatite is represented by rather numerous slender prisms, distinctly hexagonal in cross sections. It seems to be most abundant within the anorthoclase portions.

As was mentioned above there occur within the mineral basis just described some light-coloured nodules which appear to merit a somewhat closer description. In the slide investigated nine such nodules were observed, their diameters varying from 0.6 to 2 mm. They most certainly all are of the same origin and their varying development seems to depict successive stages of evolution. The common feature of them all is a large central portion that is surrounded by a narrow (0.1 — 0.25 mm across) reaction zone. The latter consists dominantly of very fine scales of calcite and, moreover, in most cases contains some anorthoclase as slender needles or spherulitic aggregates. This reaction zone is generally bounded outwards by a narrow rim of pale green chlorite and further there is as a rule observed a still narrower rim of an indeterminable brown pigment. This pigment sometimes follows the boundary between the central portion and the calcite zone, sometimes it is entirely included within the latter.

As for the central portion three different types or stages have been observed, all of which are, however, connected by transitional types. It appears as if there were some connection between the dimension of a nodule and its type of development:

1) The three largest nodules (2, 1.5 and 1.3 mm across) show a central portion consisting of a large quartz grain or an intimately intergrown aggregate of 3—5 smaller ones. The quartz is more or less intensely interwowen by veins of scaly calcite.

2) The next stage (0.8, 0.7 and 0.7 mm across) shows quartz only as one or two small grains which give the impression of being relics and are embedded by the finely scaly calcite matrix. In the latter there are also observed varying amounts of anorthoclase, forming spherulitic or irregularly bundled aggregates.

Fig. 5. Part of a partly felspathized quartz-nodule of the anorthoclase rock from Hurry Inlet. *Camera lucida* drawing. Magnification about 140 ×. Gray ≐ quartz, white = calcite, stippled areas = anorthoclase, black = brown pigment, crosses = outer chloritic rim.

3) In the next stage (0.8 and 0.6 mm across) the quartz has disappeared entirely and the central portion is completely built up of calcite and anorthoclase as described above.

4) Finally, one nodule (0.75 mm across) shows in the central part an aggregate of rather well-defined and independent grains of calcite and anorthoclase.

In the central parts of types 2 and 3 above there also occur varying amounts of the brown pigment previously referred to. In one case this pigment appears to delineate the contours of a number of pre-existent lath-shaped mineral grains which are now completely converted into calcite. A corresponding phenomenon was in one case observed within the reaction zone too.

The arrangement of the felspar-laths within the reaction zone is of some interest and is especially well illustrated by the largest nodule (fig. 5). The drawing shows, just outside the pigment-marked boundary of the central quartz, two small patches free from calcite. These patches show a radial striation or striping, the alternate stripes consisting of quartz and anorthoclase. The most important feature is, however, that the quartz of these patches is optically continuous with the central large quartz-grain.

The immediately adjacent wall-rock of the dike is represented by one specimen, No 1770, in which the actual contact may also be studied.

The rock is brownish gray and shows a medium-grained ground-mass with fairly numerous tabular phenocrysts of reddish felspar, attaining a diameter of 1 cm or slightly more.

Microscopically the ground-mass reveals a subsidiary porphyritic texture with numerous large (c:a 3 mm) irregular quartz grains and less abundant felspar grains (c:a 1 mm). The latter may sometimes show quite irregular, ragged outlines but a tendency to lath-shaped development is also sometimes observed. As for twinning only simple Carlsbad twins are encountered. The mineral is as a rule very intensely sericitized. The following diagnostical data could be obtained:

$2V\alpha = 51°$ (NIKITIN's method, average of 3 values within $\pm 5°$)
N > Canadabalsam

It seems clear, then, that this felspar, too, represents an anorthoclase.

Dimensions approaching those of the quartz and felspar phenocrysts are further attained by some irregularly rounded aggregates of iron ore dust and secondary chloritic (?) material, which most probably represent some earlier mafic mineral.

These subsidiary phenocrysts are embedded in a rather subordinate amount of an extremely finegrained ground-mass, chiefly consisting of anorthoclase. The ground-mass felspar sometimes forms aggregates of elongated crystallites. Some quartz may also be detected in the ground-mass, and, further, calcite is extremely abundant as small scales. The latter mineral also forms a few rounded aggregates of some ten individuals, the aggregates reaching a diameter of about 0.5 mm.

The large quartz phenocrysts often show corroded outlines and are invariably surrounded by a narrow reaction zone of slightly brownish tinge. The composition of this pigmented zone could not be established. Furthermore, the quartz grains are sometimes invaded by protuberances of ground-mass.

The description given above refers to the conditions a few centmetres outside of the contact against the dike rock 1767. The actual

contact line is rather distinctly marked by a sudden change of colour. This change, however, does not affect the finegrained ground-mass, which, peculiarly enough, seems to be exactly identical in both rocks. In the dike rock, however, it is richly interspersed by iron ores and mafic minerals—especially biotite—whereas in the wall rock these are all but wanting.

There can be no doubt that this rock is a product of contamination and the fact that the anorthoclase material is common to both dike and wall-rock suggests strongly that this contamination is intimately connected with the intrusion of the former. The quartz nodules of the lamprophyre most certainly were derived from the adjacent granite and their successive stages of alteration show that some chemical processes have been at work, tending to convert quartz into an calcite-anorthoclase aggregate. It seems very probable then, that the same agents have to some extent been able to permeate the granitic wall-rock, too, thereby effecting a substitution of its mainly quartzo-felspathic ground-mass by anorthoclase. It is significant that in the dike rock proper, even rather large quartz grains have been more or less completely converted, whereas outside of the actual contact only the fine-grained ground-mass has succumbed to alteration, the larger quartz grains being affected only to a rather insignificant degree. This seems to prove that the operating agents have been distinctly more active within the intrusive and thus supports the conclusion that the alteration process is directly connected with the intrusion of the lamprophyre.

The author wishes to emphasize the rather great similarity between the alteration or replacement phenomena just described and those recorded by REYNOLDS (1938) from some English lamprophyric dikes.

Somewhat similar phenomena were moreover recently described by RITTMANN (1940 p. 443) from Greenlandic lamprophyres.

In the present case the microscopical observations seem to indicate that two different processes have been at work. Firstly, the quartz xenoliths were more or less completely converted to anorthoclase as witnessed, for instance, by the alternating stripes of the two minerals in the reaction zone of fig. 5. Secondly, there ocurred a replacement of anorthoclase by calcite, which has affected not only the xenoliths but is evident also in the felspathic ground-mass as well as in the wall rock.

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APPENDIX

ON THE FIELD POSITION OF SOME BASALTS INTERMEDIATE BETWEEN THE NORTHERN AND SOUTHERN AREAS IN NORTH-EAST GREENLAND

BY

HELGE G. BACKLUND

The petrology of the Late Mesozoic—Early Tertiary dolerites and of some of its allied felsic rocks of the outer fiord region of North East Greenland between the SW corner of Traill Ø (Kongeborgen) in the South and the eastern half of Clavering Ø (Young Sund) in the North was described and discussed some years ago in two monographs (MALMQVIST 1932, 1935). Specimens from about 30 different localities within this area have been optically characterised and chemically defined by 5 + 5 analyses, of which 2 were due to the courtesy of Professor G. W. TYRRELL of Glasgow. A large collection of specimens both from North of the area indicated above (from Wollaston Forland, from Sabine Ø, and from Kuhn Ø) and from South of it (from Liverpool and Jameson Land and from the whole Scoresby Sund area except the region South of Kap Brewster—Kap Stevenson, which pertains to the investigation field of the British expeditions of L. R. WAGER) was still waiting for a closer examination with the purpose of disclosing and determining the variation range of this important and significant part of Brito-Arctic basalt region in its special and ambiguous milieu: the complex Crystalline Basement of the Early Palaeozoic Caledonians on the one hand, and its uncomformably superimposed thick and variegated plateau sediments of Late Palaeozoic and Mesozoic age on the other. While in the areas of the Crystalline Basement (at Liverpool Land, in the inner parts of Scoresby Sund) volcanics pertaining to this age group were represented by dykes of basalt only of non exceptional thickness and in more or less vertical position, the corresponding volcanics of the plateau sediments, *i. e.* those of the outer Fjord region in a broader sense, were more variegated both in their mode of emplacement as in their chemico-mineralogical development. These basalts were represented by sills, by

dikes in various positions, by flat conical sheets, by plugs and by lava beds and tuffs, while in some critical areas as *p. e.* at Kap Franklin they were accompanied by acid lavas and tuffs of rhyolitic composition. These acid volcanics, by their geological outcroppings and position plainly different from the acid volcanics of older age within the Devonian of Ymer Ø and elsewhere within the western part of the fiord sediment plateau, with its relations to the basalts, should open the possibilities of understanding and interpretation of the large and complex Tertiary volcanic area of Kap Parry—Kap Simpson, on the eastern promontories of Traill Ø, with its variegated intermixture of acid and basic magmatics both of deep-seated and nearsurface appearance. To the central Kap Simpson area, thus, a short visit was paid in August of 1933, with attendance of Professor H. E. KRANCK and Dr. TH. SAHLSTEIN-SAHAMA, while the inner region of Scoreby Sund was visited, in company with Dr. E. WENK and Mag. Sc. K. LUPANDER, during the summer of 1934.

Thenceforth the field and investigation program of the geological survey of North East Greenland was completely changed and thereby the Writer's possibilities of exploiting the compiled collections and field observations, as also of fulfilling the planned broader investigation of the tertiary magmatics and its intrusion milieu were strongly reduced.

It was thus resolved to gather all the collections of volcanics made during the Three-years' (1931—1934) Expeditions at one hand, as to warrant an uniform treatment of the material. To these collections, later on, had to be added the volcanics collected during the following Two-years' Expeditions. The research work was entrusted to Dr. A. RITTMANN of Basle and, as the first step on this way of uniform elaboration of all hands collections, appeared the "Studies on volcanic and dyke rocks of East Greenland" (1940), collected by Dr. C. E. WEGMANN and Dr. H. BÜTLER in the years 1932—34 and 1936, principally within the inner fiord region between Hudson Land (75°) in the North and Scoresby Land (72°) in the South. As there are no indications within this monograph as to an aim of extending these investigations unto the outer fiord region, and as its orientation map (*cf. l. c.* Fig. 1) does not cover any areas outside the region comprised within the MALMQVIST (1932, 1935) investigation, on the contrary, its author having expressed the intention not to touch upon collections of his own from the Scoresby Sund area, it seemed plausible to publish the above petrological investigations of Dr. KROKSTRÖM, which were planned, as mentioned above, long before Dr. RITTMANN overtook the main collections. A publication seems all the more justified as the conclusions come to by its author are somewhat different from and in contrast with those discussed by Dr. RITTMANN and former investigators with respect to the differentiation problems and some lines of descent leading to the formation of these rocks. The discrepance is the more surprising as, in

the course of descriptions of rock specimens by Dr. RITTMANN, more than once this different line of evolution of the rock series plainly comes out without its author having pointed it out nor laid stress on it.

It is, thus, the southern area of Tertiary basalts which is the theme of this investigation, and situated between 72° and 70°20′, where, conformably to the orientation map of L. KOCH (1929B, fig. 53), the Tertiary magmatic activity seems to have weakened down between its maximal developments S of the Kap Brewster—Kap Stevenson line (with total thicknesses of the piled up lava beds to 7000 m, *cf.* WAGER 1939) at the southern end, and the at Sabine-Pendulum-Shannon Ø area (with its tuffs and irregular lava beds) at the northern end of the East Greenland part of the Brito-Arctic Basalt Plateau.

Four groups of basaltic rocks are described along with the preceding investigation. Of these three pertain to the Late Cretaceous-Early Tertiary volcanics of the North-Atlantic area, whereas one, the anorthoclase rock from the east shore of Hurry Fjord, SSE of the southernmost of the Fame Øer, is decidedly older and pertains to the alnöite-ouachitite group of rocks already indicated and characterized by NORDENSKJÖLD (1909) with a short description and an analysis. The age position of this rock group, whose representants in most cases are perfectly characterized by automorphic phenocrysts of a deep brown to black mica in a rather finegrained to dense groundmass with abundant calcite predisposing the rock to an easy weathering, has been discussed more than once.—The Writer's observations may be summed up as follows: more or less vertical dikes of the rock in question have been observed cutting 1) the Hurry Fjord-granite (Devonian?) a) in the innermost part of Store Fjord (2 dykes striking NNE have been observed), b) at Kalkdalen E off the Fame Øer (about 9 dykes striking N—S have been annoted); 2) the slates and limestones of the Hurry Inlet formation (Cambro-Ordovician?) at Bodal NE of the head of Hurry Fjord; 3) the Arcose sandstone and conglomerate with pebbles and detrital masses of the Hurry Fjord granite only of Late Devonian (?) age[1]) (dyke SE of the southernmost

[1]) This sedimentary formation reposes on the Hurry Inlet granite which is reckoned as early post-Caledonian (Lover Devonian?), and it begins with a mighty and coarse, red weathering breccia; it differs by its content substantially from the Devonian conglomerates farther in the North, which nearly exclusively contain quartzitic pebbles, and of the basis conglomerates of the Lover Trias (Klitdal formation), which are composed by pebbles of granite, of various gneisses and exactly of the conglomerate in question (as double pebbles) alongside with very sparse balls of a monchiquitic rock of the alnöitic affinity. A late Carboniferous (= Early Permian) age of those Hurry Fjord conglomerates was considered more than once in the field as a consequence of its strong affiliation with a very finegrained light sandstone (SW-Liverpool Land) and of its resemblance with the conglomerate at base of the (Permian) dolomitic limestones W of the Schuchert Elv area at the W margin of Jameson Land. The last exposé of H. STAUBER (1940) approaches this latter probability quite decidedly.

of Fame Øer, striking NNE). These dykes are in their turn 1) deformed by the ROTHÉ-fault-thrust North of Kalkdalen and South of the upper Bodal, which cuts through all the geological formations mentioned under numbers 1, 2 and 3 and which dives and disappears beneath the Eotriassic sediments westward, at Ryders Dal and the Jameson Land basement; and they are 2) cut by the plagioclase (labradorite-) porphyritic dyke of more than 70m thickness opposite the southernmost skerry of the Fame Øer and pertaining to this sheet intrusion (sill). The age position of this rock group is still more narrowed by pebbles of its affinity occurring in the conglomerate of the Klitdal formation, immediately underneath the sill of plagioclase porphyrite at the second (biggest) of the Fame Øer. As the fault mentioned is older than the Lower Triassic, and there are no observations of alnöitic rocks occurring in or cutting sediments younger than those of probable Carboniferous-Permian position, the age of this rock group, whose outcrops are centered at Liverpool Land between Storefjord (71°6′) and the inner part of Hurry Fjord (at 70°45′), may be Late Palaeozoic. Whether it corresponds to some of the lamprophyric rocks described by RITTMANN (1940) from the inner fjord region in the North and whose geological position and age rests undefined, may be left undecided. From the above discussion of field evidences it comes out that this rock group has nothing to do with the Tertiary basalts proper. With its alkaline affinities, its geological connection may be looked for in the post-orogenic late-Palaeozoic block movements of the East Greenland Caledonians.

Next in age is the group of plagioclase- (labradorite-) porphyrites, whose relations to the dolerites and basalts proper of the Early Tertiary group is somewhat uncertain. Only four specimens of this characteristic rock represent the basis of descriptions, all those pertaining to the sill-like sheet at the head of Hurry Fjord, whose upper surface, with beautiful fluidal arrangements of the tabular feldspar phenocrysts, forms the undulating top platform of the Fame Øer, whose total thickness represents its precipitous shorecliffs, and whose continuation in the north, on the eastern side of Ryder's Dal, enters in the pink arkose sandstones at the base of a row of hillocks with steep slopes to the east and gently declining westward, which are characteristic of the Klitdal or Lower Trias formation. On the Fame Øer the westward dip of the sill is somewhat irregular, while in Ryder's Dal its dip develops in complete concordance with the famous westward sloping gneiss surface of the western Liverpool Land basement, lately once more mentioned by ROSENKRANTZ (1942).

There are some detail behaviors to annote concerning the field appearance of the Fame Ø sill. The observations are chiefly made on the northernmost of these islands with its rolling and stepped, some-

what bulging topography, representing the surface of the sill itself; it is lowest in the W and SW, highest in the E and NE. On the southern shore there are to be seen two distinct beds (sills) of porphyrite, the uppermost (about 3 m thick) separated from the lower one of unknown thickness by an intercalation (about 2 m) of grey arcose sandstone grading unto finegrained conglomerates, with gray limestone closest to the roof and the floor of it. The upper bed at its lower contact and the lower one at its upper contact contains a row of limestone lenses as inclusions (limestone of this purity is not met with otherwise in the normal Fame Ø profile of Lower Trias sediments of the Klitdal formation) and from each basalt surface in its order small apophyses of a dense black rock intrude the sediments upward and downward respectively. At the other sections of these islands only one single sill is to be seen: the section just described may represent a well dimensioned inclusion, as well as in the steplike depressions of the present porphyrite surface remnants of encased sediments are met with elsewhere. The perfect plane of the upper surface of the porphyrite sill immediately develops a coarse grain with tabular phenocrysts of labradorite until 5 cm across, arranged conformably with the surface plane, but locally in rows turning on the edge herewith marking flow movements. Only a small number of dense black, well defined, somewhat later intruded apophyses are observed on this surface, which is cut by regular, broadly spaced and vertical joints at right angles.—On the second island, the largest of the five, the eastern and northeastern shores expose perfect profiles of the flooring sediments with heavy conglomerates containing *i. a.*, as mentioned before, scarce pebbles of the Late Palaeozoic volcanics, while on the northernmost cape the sill exposes its full thickness—about 18 m. The 3d and 4th islands consist wholly of porphyrite, while on the southernmost smallest one underneath the sill there crops out an arkose sandstone, by heat (?) transformed to quartzite.

Besides the sill of the Fame Øer area there is the mighty dike (more than 70 m thick) in its Southern continuation (about 250 m long) which cuts Lower Palaeozoic rocks including the Hurry Inlet granite and probably also the Upper Palaeozoic dykes discussed above, with a poor contactmetamorphic action only. All these observations give no direct hints to the age position of these porphyrites except that they are later than Lower Triassic. Yet in the North, at Kap Biot, on the south shore of Davy Sund, at its base, there was observed within sediments of presumably Lower Triassic age, a nearly aphanitic black plagioclase porphyritic sill, which is cut by a fairly fine-grained basalt dyke of the main Early Tertiary type. Porphyrites of similar development are outcropping as sills elsewhere in the Fleming Fjord area i. e. behind (S of) Kap Seaford and probably along the W-shore of Carlsberg

Fjord, always confined to the lower parts of the Early Triassic sediment piles. Thus, both the low position within the Mesozoic sediments and the critical intersections elsewhere in these sediment areas South of Davy Sund plainly affirm a somewhat higher age of the plagioclase porphyrite with respect to the main group of the Tertiary volcanics. North of Davy Sund, in the Kap Simpson area, occurrences of this coarse porphyrite seems to have been met with also in smaller extensions (cf. hereto SCHAUB 1938, 19).

The olivine dolerite and basalt, the most typical, proper Tertiary group, is by far the best represented both by specimens studied and by outcrops in the field. There are no essential differences between rocks named dolerites and those named basalts; the marginal parts of sills and cutting dykes of small mightiness by its texture may be classed as (olivine-) basalts, while big sills and well proportioned dykes in all respects are to be discussed as olivine-dolerites.

The most prominent representants in the field of this group are the perfect sills along the western shore of Hurry Fjord within the Mesozoic sediment area of the eastern Jameson Land, i. e. at the famous Neill Klinter (Pl. 1.1). They can be traced, with some (real or apparent) interruptions, from Kap Stewart at its southeast corner (here near sea level) to the southern surroundings of Nathorst Fjæld, along the steep Neill Klinter gently gaining in height and interrupted only at spaced intervals by erosional creeks ("Klöft") and thereby disclosing occasional local complexities of the sill position and its alleged dykes. These sills, of nearly half a degree of striking length of a continuous outcrop, represent one of the finest field examples of a sill intrusion. Beneath a cover of sediments of more than 400 m and within a sediment pile at first sigt completely undisturbed they keep, with small jumps here and there, nearly insensible to the inspecting eye, the horizon as perfectly as if they pertained to the sedimentary formation itself (*cf.* Plate 1, Fig. 1), and they are nicely comparable with the sills of the Eastern Spitzbergen area (within sediments of similar age position and facies development at Edge Land, figured *p. e.* by RAMSAY in his textbook of 1909 on p. 96), which by the famous A. E. NORDENSKIÖLD were lately exploited as a last nature's argument in favour of a "neptunistic" origin of these basalt "beds". A detailed field investigation of the basalt sills, however, on both localities reveals their inconstancy of horizon, but ratifies in most cases only inconsiderable contact influence within the border rock both upward and downward, although the intrusion itself represents a very long-lasting process (because of lack of greater disturbances!) and expresses an enormous amount of labour and a very great heat transfer, which should find, after common judgment, a considerably more adequate

expression by a simple central outburst of the ascending magma. Nathorst Fjæld, too, is intruded by some slightly irregular sills at different heights above sea level, although northward, at the western slope of Ryder's Dal, along the continuation of Neill Klinter, regular sills are certainly outcropping as manifested too by the Desert Mts (Noe-Nygaard 1934) at the head of Fleming Fjord and within the shores of the fjord itself. The western shore of Carlsberg Fjord too shows conditions favorable for sills' outcroppings.

The following list of height numbers (Table 1) gives an idea of the vertical distribution of these sill intrusions along the erosional border indicated by Neill Klinter in the South, and the western shore of Fleming Fjord in the North. The list is compiled principally from the more or less occasional observations of Rosenkrantz (1934, 1942), Noe-Nygaard (1934), Aldinger (1935) and partly from some of the Writer's field annotations.

The two tables (Table 2 after Stauber 1940), in which the figures of height arranged within four, *viz.* seven, vertical columns are considered to pertain, each of them, to the same sill intrusion respectively, and from which it is plainly visible that at different sections the sills are substituting each other without strong correspondence, display the tendency of the sills in general to associate throughout heavy sedimentary piles and nevertheless to persist within a constant stratigraphical level without being fixed exactly to the same horizon. However, the figures of the two tables which represent only approximations, are not comparable in detail because of being related, in their right halves, to different levels of references, *i. e.* to the top (Table 1) and to the floor (Table 2) respectively of the Rhaeto-Liassic formation, whose mightiness varies broadly, according to the thorough investigations of Stauber (1940,1942), from one locality to the other, being in general a continental formation.

There is no intention, from the Writer's side, to encroach upon the excellent and masterly observations of Dr. Stauber, nor to anticipate some conclusions of his announced within his preliminary report of 1940. The scope of the following discussion is only to point out some problems which more than once and since more than a quarter of a century urged the Writer during repeated reconnoitrements of the basaltic sills of Eastern Spitzbergen (1907, 1921), of Northern Siberia (1920), of Eastern Patagonia (1923, 1926) and last but not least, of the Jotnian Sandstone areas of Fennoscandia (1938). The problems lately presented themself during a personal inspection, in 1933 and 1934, of the eastern, southern, western and northern borders of Jameson Land. The impressions were revived, some years before (1929, 1930, 1932), by the study of the basalts of the outer fiord region of East Greenland, North and South off the

Table 1. Summary of basalt sills' position in Jameson Land along its Hurry Fjord border.

Sections	Distances fr. Kap Stewart	References	Heights (approx.) above sea level (and thicknesses)				above top of Rhaeto-Liassic			
			1	2	3	4	1	2	3	4
1. Kap Stewart	ab. 200 m	R	..	..	..	0 (?)	..	..	..	— 10
2. Ræveklöft	- 2.6 km	R	..	..	..	84 (6)	..	..	..	+ 65
3. Tancrediaklöft ...	- 4.4 -	R	..	..	..	168 (?)	..	..	..	+ 84
4. Dinosaurusklöft ..	- 6.3 -	R	184 (?)	..	..	233 (0.5)	+ 45	..	..	+ 95
5. Albuen..........	- 13.7 -	R	277 (2)	290 (0.5)	425 (1)	447 (9)	+ 75	+ 88	+ 222	+ 245
6. Goniomyaklöft ...	- 15.6 -	R S	..	315 (2)	..	370 (10)	..	+ 88	..	+ 140
		R N	273 (?)	307 (?)	..	357 (?)	+ 46	+ 80	..	+ 130
7. Vardeklöft........	- 16.9 -	R	258 (12)	300 (3)	..	348 (10)	+ 55	+ 97	..	+ 120
8. Astarteklöft	- 19.6 -	A	304 (20)	365 (1)	..	490 (18)	+ 136	+ 197	..	+ 322
9. Muskokseklöft ...	- 21.9 -	A	238 (3)	299 (?)	483 (3)	?	+ 77	+ 138	+ 260	+ 300
10. Nathorst Fjæld ..	- 41.3 -	R	168 (6)	300 (2)	..	..	— 218	— 86	..	..
11. Desert Mts. Fleming Fjord	- 90 -	N–N	..	145 (?)	235 (?)	320 (?)	..	below	below	below
12. Kekertak Isl. Fleming Fjord	- 115 -	N–N	..	0 (?)	..	..	..	below	..	..

Franz Josef Fjord area, and the problems were further stimulated by the inspection of the western basements of the imposing and perfectly concordant basalt pile of more than 7000 m thickness south off Kap Brewster and Kap Stevenson (1934), as to the mechanics of intrusion controlling the East Greenland basalt region and of sills in general.

Dr. Stauber points out, that some of the sills, *i. e.* No. 5 on the one hand, No. 6 and 7 on the other hand (Table 2), can be traced without essential visible interruptions as a continous sheet, from Gurreholm Dal in the South-West over Ørsted Dal in the North to the western slope

Table 2. Summary of basalt sills' position in Jameson Land along its western and northern border (approx. after STAUBER 1940).

Sections No. and situation	Heights (approx.)													
	Above sea level (and thicknesses)							above floor of Rhaeto-Liassic						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
. S. Schuchert Elv (Gurreholm Dal) W-E	..	..	..	..	190 (40)	..	330* (2)	..	..	..	..	+130	—	+270*
. N. Schuchert Elv (Gurreholm Fjælde) W-E	80 (1)	290 (5)	410 (15)	450 (40)	860 (100)	1060* (10)	1200* (10)	—680	—470	—350	—310	+100	+300*	+440*
. Ørsted Dal (W Fleming Fjord) S-N ..	..	..	225 (30)	640 (60)	750 (10)	860* (15)	1010* (40)	..	..	—225	+90	+200	+310*	+460*
. Grænsedal (W Antarctic Havn) N-S ..	..	70 (?)	..	..	..	770° (10)	800° (20)	..	—265	..	..	—	+435°	+465°
i. Kap Biot (N Fleming Fjord) SE-NW	..	..	130 (1)	..	?	..	..	..	..	—470	..	above	..	..
i. Pingel Dal (S Fleming Fjord) W-E..	..	..	..	..	875 (10)	..	..	..	..	..	..	+75	..	..

* Plagioclase porphyritic basalt.
° Light coloured (acid) volcanics.

of the Klitdal valley and unto Nathorst Fjæld at the head of Hurry Fjord, *i. e.* to the eastern border of Jameson Land. This means that these sheets dive continously beneath the sediment pile of Middle-Upper Mesozoic formations of the whole Jameson Land basin. The sill No. 5 represents a (olivine-) basalt of the usual plateau basaltic type, while the sills No. 6 and 7 are plagioclase porphyrites of the same coarse type that constitutes the platform of the Fame Øer and the bottom sill of Ryder's Dal (described on pp. 21—40, but not entered in the Table 1), and the lowermost sill (No. 1 of Table 1) of Nathorst Fjæld. The sill No. 5 (Table 2) has not been met with within Grænsedalen, while the sills No. 6 and 7 could be traced even in Grænsedalen, partly as lightcoloured, acid sills. Now the plagioclase porphyrites of the western border of Jameson Land occupy the uppermost position of the whole sill suite within the sediment pile, while those of the eastern border are the lower-

most ones. The Fame Øer porphyrite sill and its Ryders Dal continuation occurs a couple of ten m above the crystalline basement, and partly, in its southern continuation, sinks below sealevel, while in the west, at Gurreholm Fjælde (section 5), the corresponding sill (No. 6) rises to more than 1000 m above sealevel. Meanwhile this sill (as also the higher one) changes its stratigraphical position in the East from brackish-marine Trias (= Klitdal Formation) some 600 m upward unto the top half of the Rhaeto-Liassic in the West. The uppermost plateau basaltic sill in the West (No. 5), however, occurs below the porphyritic ones, and some 300 m or more below the top of the Rhaeto-Liassic, while in the East the lowermost basaltic sill at Nathorst Fjæld occurs above the 2 porphyritic ones, at approx. 80 m below the same top, consequently holding approximately its stratigraphical level. The rest of the sills in the East, being basaltic ones, except the uttermost Kap Stewart basalt, occur far above the top of the Rhaeto-Liassic, while in the North-East the basaltic sills at sections 11 and 12 (Table 1), which by the way from evidence specimens are non-porphyritic (*cf.* NOE-NYGAARD 1934) but plateau-basaltic, occur below this top.

From the above locations, both in horizontal and vertical sense, it becomes evident, that the uppermost basaltic sheet (No. 5 of the Table 2) does intersect the porphyritic sill-sheets (No. 6 and 7) somewhere around Fleming Inlet in the North-East. From the field observations there is, moreover, reason to believe that the porphyritic sills are older than the basaltic ones, and the petrological and chemical discussions (*cf.* KROKSTRÖM, above) involve the same conception. Hereto they point out that the porphyrite may pertain to an intrusion distinctly separate, because the relationships of its "magma" to the plateau-basaltic one are plainly deep-seated. Hence the onward conclusion lies at hand, that the general conditions of sill intrusion have changed during the time interval between the oldest porphyritic intrusions and its pure basaltic sequel. If the remainder of the plateau-basaltic sills in upper stratigraphical levels along the eastern border of Jameson Land may pretend to be correlated in age with those at descending horizons of the western border, it turns out that the more the sills climb to the top of the sediment's pile in the East, the deeper down they dive below the critical level zone of the Rhaeto-Liassic in the West. The intersection of the planes of the sill's intrusion inaugurated by the next oldest plateau-basaltic sill still continues, and its angle of intersection increases steadily according to the forthcoming development. This means that the changed conditions of intrusion pointed out above, as indicated by the change of intrusion plane, are continuously being sharpened in the same sense as during the continued sill evolution. The intersection or hinge line of these intrusion planes seems also to change its orientation continously.

Now, the change of orientation of the intrusion planes, to begin with fairly abrupt, thenceforth more continuous, may develop in some interrelation with the full-trough sliding of the Mesozoic sediments within the Jameson Land basin during its Tertiary evolution, as discussed by STAUBER (1940, 1942), and, with respect to the neighboring Traill Ø area, under somewhat different conditions, by SCHAUB (1937, 1942). The interrelations may be of a very complicated nature and ask to their enlightenment for some further clarifying discussions about the general conditions of these sills' emplacement.

There are no proofs so far of the rightfulness of correlating the upper suite of basaltic sills at the eastern Jameson Land border which occur high up in the Upper Mesozoic sediments and thus justify after all a presumed later stepwise emplacement, with those of the lower suite along its western border; these in their turn descend far down into the permian sediments (cf. STAUBER 1940, map and sections; see also Table 2, section 5, sill No. 1, located 680 m below the floor of the Rhaeto-Liassic) and thus merely should develop an inverted order of intrusion, unexpected and unusual to a current field imagination. To approach some general understanding of the whole complex of interrelations it is to begin with necessary to fix up some intrusion questions, as 1) the formal foundation of the sill intrusions, 2) their location with respect to the basin of sill evolution, and 3) an approximate estimation of the quantities produced by each intrusion. Then it is necessary to consider the changes of level or differential movements with vertical components within the broader and narrower neighbourhood of the area of basalt evolution, with its direct or indirect relations to the basaltic emplacements. Only later can the question of correlation of the remaining sills at the eastern and western borders of the sedimentary basin and of their mutual influences at the sediments' sliding be considered.

STAUBER supposes that the feeding apparatus of the sills is represented by more or less vertical dykes of which a great number have been observed within the area considered. He points out that these supposed feeders, as suggested by special maps of Kap Leslie (north-eastern part of Milne Land) and of the southern part of Jameson Land (ALDINGER 1935), preferably strike in E—W, i. e. transverse to the sedimentation basin. He suggests a similar joint direction preferred by basalts, within the adjoining crystalline areas as marked by the great transverse fjord tracts. Now within the considered sediment areas on the maps cited above there are plenty of (more or less) vertical dykes deviating from the E—W direction. Nor does a compilation of observed data on basaltic dykes (for part of which cf. the above description) confirm this suggestion as seen from following figures chosen more or less at random:

Table 3.

Areas	Localities	strikes	dips	thickness
East off: Liverpool Land	N. off Storefjord......	NNE	W steep	about 3 m
	Kap Smith	NW	NE -	- 4 -
	Bodal	ENE	vert. ?	?
	Hodal...............	E-W	- ?	?
	Opp. Fame Øer	NW	- ?	70 m
	Kap Hope (cutting Upper Jurassic Sediments)	WNW	SSW flat	10 -
		NW	NE 60° to vert.	7 -
		NNE	E.st.	2 -
		E-W	S $\geq$ 54°	60 -
West off: Inner Scoresby Sund	Sydkap.............	E-W	S ab. 45	about 6 m
	Flyverfjord	NE	NW steep	?
	Mt. Reinhard (NW-Fj.)	NNW	E ab. 60	about 10 m
	Rype Fjord (red sed.)..	NW	SW flat	— 4 -
	Røde Ø (young red sed.)	E-W	vert.	— 2 -
		N-S	-	— 6 -
	Milne Isl. W-corner....	NE	NW steep	— 10 -

The figures of thicknesses of Table 3 hardly admit any interpretation of the observed dykes as being feeders of larger sheets of principally horizontal extension: they are to small for such a task. Only two of them, *viz.* those along the eastern shore of Hurry Fjord, at its head and at its mouth, are of such extraordinary thicknesses (70 and 60 m respectively) and of inconsiderable, yet unknown striking lengths as to be suspected for feeding functions. Yet they can hardly pretend of being called dykes with regard to their restricted length (the northern one especially), they are merely plugs or bosses. However, it seems improbable that dykes which cut the horizontal plane at angles deviating considerably from 90° are capable of serving as feeding channels of intrasedimentary sheets with dimensions of the mentioned sills and with its complicated intrinsic mechanics. Moreover, the dykes within the sediments (as also occasionally within the crystalline basement) are often winding, as already pointed out by ALDINGER (1935), and therefore hardly capable of producing any considerable surplus of molten material. In most cases their thickness is too improportionate of running such a complicated sill mechanics as the one described above. In cases of exploiting preexisting joints or faults a dyke intrusion with such a validity as to expand horizontally with a thickness of 100 m throughout hundreds of square km certainly should prefer to develop as a surface action according to the law of minimum resistance and slightest labour. The mechanics proposed by STAUBER (1940) is dif-

ficult to realize as to explain this sill-formation, even if a potentialised slope gradient by one-sided upheaval should enter in the system as an extra factor. It touches upon a circulus-demonstration. The Writer's field experiences, more than once precisely in the (northern) Jameson Land sedimentary area too, show that none essential surplus transport of molten basalt matter has been effectuated through dykes in vertical position, because occasional inclusions (as *p. e.* pebbles of conglomerate sheets, cut by the dyke) in its very central part have suffered nearly no transport and still indicate the shattered conglomerate horizon transverse to the dyke. In the sedimentary basin, therefore, one may suppose that the dykes are serving preferably some adjustment purposes during the complicated processes of a sill intrusion. An instructive representation hereof presents the northern Hurry Fjord part of Neill Klinter (*cf.* profiles of ROSENKRANTZ 1934), as also the winding E—W dykes of southern Jameson Land (ALDINGER 1935).

Now, within this field there occurs a number of basalt bosses (= Stöcke, ALDINGER) with a rounded circumference in the horizontal section. Their rôle is somewhat uncertain, if the dykes be of one or the other function (cf. above), and they appear superflous within the mechanics of supposed feeding dykes; their relations to them are greatly obscured. ROTHÉ (1934) expressed the opinion that the volcanicity, the big sills also included, of the Scoresby Sund area was originated by vertical magma channels protruding through the sediment piles as rough bosses; he believes to have traced both by magnetic and gravimetric surveys such a dimensioned channel-boss at the sea-bottom South-South-East off the mouth of Hurry Fjord. In the northern basalt area of Clavering Ø the Writer (1932) tried to explain the somewhat irregular sill appearance of the basalts as an intrusion into the sediment pile at relatively shallow depths of flat conical sheets. The irregular clustering of imperfect sills around a more or less central boss or plug leads to this conception. It is obvious that at a certain depth a boss intrusion, with a certain dropping (?) energy entering into a predisposed (by banking) sedimentary *milieu* may expand as a sill—the amount of water mobilized by the intrusion may cöoperate—without essential conical accomodations, while at another (higher?) level with different amounts of expanding energy, gaseous mobilisations and somewhat differing sedimentary accomodations more or less typical shallow conical sheets (flat or steeper) may result. It has been pointed out above that a sill intrusion may be realized *i. a.*, if sufficient amounts of heat is disposed of by a feeding apparatus and if this apparatus is apt to transmiss a maximum amount of basaltic matter with a minimum of friction and heat losses, *i. e.* with a minimum of labour expenses. It is a cylindrical feeding channel which corresponds most perfectly to such conditions in all related essentials, while an

ordinary dyke exposes too great surfaces to maximal heat losses, as also its internal friction conditions prevents the affluence sufficient to overwhelm the overplus friction along the horizontal planes and to support the tremendous load of the hanging sediments without any notable heat excess (*cf.* the insignificant contactmetamorphic action of the sills in general).

Thus, the probable shape of the feeding apparatus of the sills having been defined, it becomes more or less plausible why such feeders really are rare of observation. The special pressure conditions characteristic of each sill intrusion emphasizes the probability of the sill having its own single feeder apparatus because the realisation of two simultaneous feeding channel systems with exactly equal potentialities of heat transfer and transportation possibilities to meet at the same sill level seems too complicated a system in connection with a "magma chamber" in evolution. Now, it can hardly be doubted that around and nearest to the feeding channel the sill acquires its maximal thickness, with a gradual fading —until some minimum thickness—appending of the heat available. In erosional exposition of the whole complex—with only small changes of its initial horizontal position—the feeding channel becomes thus visible only after destruction and denudation of the whole sill and its enclosing rocks, and then its primary functions and purposes become unintelligible, because its general alliances are destroyed. Only occasionally, if the sill-intruded sedimentary complex being dissected by faults, whose orientations and positions are in some way dependent on the position of the feeding channel, this important apparatus may be exposed immediately by the fault system or by its directed retrograde, one-sided erosional work. This collocation of crossing faults and of a feeding apparatus induced the Writer (1907) to connect the causality in inverted order, *i. e.* to interpret the faulting as an introductory act of the sill's intrusion, whereas the faulting is decidedly younger and so far independent of the intrusion act proper.

Having now approached the probable explanation of the formal foundation of the sill intrusion (p. 63, sub 1), *i. e.* of its feeder's shape, it is perhaps permitted to apply the conclusion in inverted order: the thicker the sill in question, the nearer the feeding apparatus (p. 63, sub. 2). An inspection of Tables 1 and 2 immediately reveals that the sills of the western border of the Jameson Land area are mainly thicker than those of the eastern one (*cf. p. e.* section 5 of Table 1 with section 5 of Table 2). An exception represent the plagioclase porphyrite sills (Table 2, No. 6 and 7), whose thicknesses are rather uniform throughout the whole area, with a lean maximum in the North (15 and 40 m respectively) hardly allowing any secure conclusion other than perhaps

a northern location of a feeder. Their merely constant and uniform relative proportional heights in the West indicate a level position of the reference plane at the intrusion time and the abrupt dropping of the intrusion level in the East (Nathorst Fjæld and Fame Øer) seems to point at a higher position there of the sediments and their crystalline basement at the same occasion of intrusion. Reckoning from sill No. 5 downward (in the West, Table 2) the maximal thicknesses of sills seem to be represented in the West (*cf.* section 5), and the intrusion plane, judging from the proportional height figures and compared with conditions of No. 6 and 7, is a more deformed one, the deeper one descends in the sediment pile. Simultaneously, the present absolute height of the sills rises to top figures in the West. On the other side, eastward (Table 1) the proportional height figures show the slightest variability within the lowermost sill (No. 1 and 2) and the greatest one with the widest sway within the uppermost sill. The absolute heights of the sills, on the contrary, remain at moderate heights. These statements seem to confirm the difference in, and inversion of, order of intrusion at the western and eastern borders tentatively proposed above. They point at a location of the feeding apparatus of sills No. 1—5 somewhere along the western border (Stauber 1940).

Now, the further exploitment of the Tables, which once more be relieved are composed somewhat at random, leads to the following observations. It has been pointed out that the oldest two sills (No. 6 and 7, Table 2, corresponding to sill 1 of section 10 in Table 1 and to the Fame Ø sill) have delivered considerable magma masses quite uniformly throughout the whole area, perhaps with a small regional surplus in the North, with a sensible decrease in the South-West (Section 7: South Schuchert Elv) and with a probable total fading out in the South-East (mouth of Hurry Fjord). The slight gradient resulted herewith favours the possibilities of minor southward slidings, elsemere an erosional exposition in the north and increasing sedimentary thicknesses in the South-East. The succeeding sills sharpen the gradient from the West, not only by their increasing thicknesses, but also by the accumulating energy of repeated invading masses, thus augment the eastward sliding possibilities. The erosion possibilities still increase gradually in the West, the sediment thicknesses augment in the East. The sill regimen, keeping still the same order of events, *i. e.* amongst others a constant and equal intrusion distance of the casual land surface, opens intrasedimentary planes for entrance of the magma sheets at gradually deeper stratigraphical levels in the West, at stepwise rising stratigraphical levels in the East. The consecutive and latest sills both in the West (No. 1, Table 2) and in the East (No. 4, Table 1) show decreasing and

morphic Complex of Late Caledonian age) far outside the vaste basaltic region, which statement is confirmed by WAGER. The top sediments of the Series are baked and considered by BÖGGILD to represent volcanic tuffs metamorphosed by the basalts. WAGER confirms their baked appearance without pushing on metamorphism, but he decidedly denies their tuffitic origin, determining them as true yet somewhat peculiar sediments. USSING (quoted again by WAGER *l. c.*) determines its bottom conglomerate as consisting principally of basalt pebbles and thereof concludes an infrabasaltic age and position of the sediments. WAGER (l. c.), on the other hand, settles that the pebbles and their matrix are composed by rocks completely alien to the basalt suite and that they are reposing on a absolutely fresh basalt basement without any traces of its weathering or erosion. Therefrom he concludes that the sediments were laid down on top of the fresh basalt surface immediately after its emplacement and that afterwards they are thrown down by faults unto their present position. He does not deny the occurrence of basalts later than these sediments, yet he is aware of the difficulties aroused by his proposed solution as expressed by the following quotation (*l. c.* p. 27): "It is difficult to understand how basalt detritus could be so completely excluded from the Middle and Upper Series at Kap Dalton unless all the basalts of the huge area to the West and North were at that time covered by the sea. If this had happened, it is surprising that the sea at Kap Dalton, which would then be far from the coast, remained apparently shallow. The most satisfactory hypothesis to explain the facts seem to be that the Jameson Land syncline was already active and uplift of Liverpool Land had also begun. We shall see below that there is some evidence that the alkaline basalt etc. of the basal conglomerate came from lavas which once covered the region about the entrance to Davy Sund. When these had been removed, Mesozoic sediments below the basalts, and at a later stage the Metamorphic Complex of Liverpool Land itself, would provide the material which forms the Middle and Upper Kap Dalton Series."

There are further three remarks to quote, as to augment the difficulties already cited: 1) There are no outcrops registered of the alkaline rocks with which the pebbles of the bottom conglomerate of the K. Dalton Series are compared and from which they are reckoned to derive; only occasional beach pebbles of remote resemblance and of uncertain original field position met with at localities North of Davy Sound are exploited for comparison, whilst the Tertiary igneous rocks other than basalts of Kap Parry—Kap Simpson (eastern parts of Traill Ø), from which the beach pebbles are supposed to originate, seem to pertain, so far known, to another petrological association and are later of appearance than the basalts (SCHAUB 1938; the Writer's experiences

from 1934, BACKLUND 1937). However, the distance from Kap Dalton to Kap Simpson, as the crow flies, is more than 300 km. 2) Outcrops of dykes certainly pertaining to the same association as the pebbles of the K. Dalton Series bottom conglomerate are met with within a much closer range, at central southern Liverpool Land (NORDENSKJÖLD 1909, KRANCK 1935, KROKSTRÖM and Writer above), namely representants of the Ouachitite-Alnöite-Monchiquite Series of convenient age position to mix up with gneiss derivatives; the difficulty still persists from the statement, that they occur below the mean basalt level. 3) It seems perhaps strongly inconsistent to let the big basalt masses of the Blosseville Coast sink down below the sea level for the sake of emplacement on top of it of some 300 feet of sediments, whose long distance transport along a basaltic (coastal?) basement is performed without any essential erosion effect, *i. e.* without any admixture of the basaltic material of its basement. The more so surprising as this transport was executed during an observed longlived volcanic activity, which along the other parts of the same coast was persistently accompanied by rising tendencies of the whole affected area; thus also sinking repeatedly to meet the necessity of depositing similar sediments probably of different age at different levels of the suite of the basaltic sheets. As concluding act then, after ceased volcanicity and the last upper basalt sheet superimposed still about in sea level, the immense pile of basalt sheets jumps upward to lofty heights and unto exposing its crystalline basement (at Gaasefjord in the West).

In West Greenland, at the Svartenhuk-Nugsuak-Disko region, the classical exploration field of STEENSTRUP (and A. E. NORDENSKJÖLD), whose similar position and analogous evolution for the first time for broader tectonical purposes was consequently exploited by L. KOCH (1929, 1935, 1936), the evolution of the resembling, still more imposing basalt piles was explained after the pattern of WAGER (NOE-NYGAARD 1942), with addition of some discussion of the geophysics of this kind of isostatic adjustments. One wonders perhaps how this adjustment operates, beginning with gradual downwarping to sea level during the change of place of the heavy basalt lava from the depths of the "magma basin" to the level surface, and then after a good time's work, inaugurating the inverse process of heaving the top-seated basalts with its basement to lofty altitudes, the crystalline basement becoming fixed again approximately at sea level.

Now, ever since WERNER's and L. v. BUCH's days the absolutely parallel-bedded piles of basalt sheets of extraordinary total mightiness (in the case of W. Greenland one speaks of 10,000 m), especially of Tertiary and earlier age, have been considered as an example of a geological formation, whose origin and construction cannot be explained from a

Uniformistic (Actualistic) point of view. They were also, because of their absolute horizontality, of course, their enormous areal extension and the uniform thickness and composition of their individual beds, among the latest defense works of the Neptunistic phalang of geological thought; the more, there were no tuffs or other volcanic products than basaltic lavas present with the piles and no visible feeders or affluent channels to be located. But lately it was pointed out, that the piles are not absolutely devoid of conformable tuff intercalations as to manifest explosional interruptions of the else uniform and quiet volcanic action. Yet the examples cited above, where thorough investigations of highly competent specialists of intense special and local training lead to different results (tuffs or straight going sediments) as to the definition of certain sheet members within the basalt pile, may serve as a strong warning against non impartial, desired solutions. These areas have also been compared with the "flood basalts" of TYRRELL, thus their origin being comparable with a water sheet flooding some alluvial plain. This comparison is only valid if the flooding water sheet is acting at air (and basement) temperatures far below the zero point and then, certainly, no regular sheet is to be formed. The Quaternary and modern basaltic eruption fields are so unlike the Tertiary piles of *p. e.* Greenland as the total view and general plan of a modern city are like one the other after and before an airplane raid.

To meet the demand to cover, as in the case of E- (and W-) Greenland, extraordinary wide areas there is need of a basalt lava of great fluidity, *i. e.* of high temperature, hereto an absolute perfect plane, preferably with a slight gradient. In nature, within the lava piles, there are no sure primary gradients visible; a lava pool on a plane would produce a flow capable only to stem up concentrically at short distances of its origin; the same effect is given with a linear feeder: a stemming up of a linear wall would be the product. The variable thicknesses suggest variations of temperatures and compositions from one individual sheet to the other. Meanwhile no physical nor chemical differences of indicated dependences can be detected within the piles and their sheets. To meet the demands of absolute horizontality of the flood basement one is disposed of letting the flooding act perform near or at sea level, perhaps with the reservation too, that the extending basalt may form a sort of emulsion with the water or its shallow mud sediments. None such process can be traced within the basalts nor in their neighbourhood. Nor are there bigger chances of building up such a regular suite of uniform sheets at the sea level than elsewhere because of the chilling action of the water. It is the characteristic speciality of these pre-Quaternary basalt piles that one can follow a sheet exactly as a leading horizon within a sediment profile for miles and other miles without meeting an interrupting

dike and without annoting any irregularity; then comes a sudden jump, the sheet changes level exactly as sills within sediments do; or the sheet thins out and disappears without any tracks of the characteristic details of a lava stream's end; or after tens and other tens of km there appears unexpectedly a dyke, mostly oblique and much too insignificant as to serve some feeding purposes. Real feeders, *i. e.* dimensioned stocks or bosses, or dykes of respectable thicknesses, are not met with at all along the precipitous northern coast.

One cannot repress the impression of an individual likeness in behaviour and appearance between a single sheet of such a basalt pile, on the one hand, and a perfect sill within a banked horizontal sediment series, on the other. In principle four topics, which remain unsoluble with the conception of "flood basalts" in the case of South Scoresby Sund, become rather solvable by a representation of sill intrusions in shallow sediments immediately above their basement to begin with, and then forthwith, at the sequel of emplacements, directed by the first one with its possible erosional consequences:

1) The intercalated sediments may be of whatever age, if they are preserved at an undisturbed horizontal position; they are, as a rule, older than the basalts, and their sedimentary material shows no connection with, nor derivation of, the basalts of the footwall or of the roof. The contact influences are, as quoted more than once in case of true sills, insignificant and often hardly perceptible. These statements seem to fit well with the case of the K. Dalton Series.

2) The horizontality and the equality of thickness of the individual sheets is governed, in first order, by the horizontal sediments, *i. e.* by their banking and by their thickness or vertical distance from the casual landsurface. In second order, it depends on the smoothness and flatness of the crystalline (or other) basement. The consecutive sheets are fairly governed by the basalt already emplaced, and by an eventual amount of erosion of the top formations. In the case of the Kap Brewster —Kap Stevenson area the crystalline basement of the basalt pile, which appears at sea level on the south shore of the inner Gaasefjord and rises to the top peneplane at ab. 2000 m above sea level in the southern Milne Land, is nearly absolutely smooth and flat. At the eastern end of Milne Land (Kap Leslie area) it is thrown down by (older?) faults and covered by remnants of Upper Jurassic sediments (Oxfordian, ALDINGER 1935).

3) With the proposed kind of evolution there is no need for letting the complex sink during the basaltic emplacements with purpose to hold these at sea level, and thereafter to let them rise to the lofty altitudes characteristic of today. The upheavel may be gradual and stepwise

throughout the whole emplacement process and culminating with the closure of the volcanicity. Basaltic volcanic actions of plateau type are always a process of disturbing the isostasy, nowhere they are the result of isostatic readjustments.

4) As mentioned before, the basalt piles, as represented by the Blosseville Coast and its Scoresby Sund continuation of East Greenland, being of Tertiary age, are without correspondence within modern times. In the proposed kind of genesis the exemption of the same and its analogies from the application of the Uniformistic Principle seems superfluous, because these prominent buildings of Nature have been formed beneath the surface in case and therefore their process of modern formation is exempt of the control of today.

The proposed explanation of the happenings around some of the most imposing marvels of Nature may be thoroughly controlled in the field. Other basaltic areas of pre-Quaternary age and of resembling representations may succumb to analogous explanations. One may render account of the enormous heat transfer produced in the central parts of such basaltic stockworks. And one may realize that such a transfer contributes to the mobilization not only of minor (molecular etc.) emanations, but also of major bodies, allied geologically with the basalt and more or less contaminated in the course of events. It seems probable that the acid and felsic mobilisations of Kap Parry and Kap Simpson in the North of the area considered (BACKLUND 1937, SCHAUB 1938, 1942), of Kangerdlugssuak in the South of it (WAGER 1939) of East Greenland, those of Ubekendt Island of West Greenland (STEENSTRUP 1883) may belong to this type of connection and genesis; yet also some liparitic and granophyric representations in the older parts of Iceland (BÄCKSTRÖM 1891, HAWKES 1933) may have developed by some similar derivation. On the other hand, one is tempted to suppose, that at the end of such an intense subterraneous basaltic superposition the area involved may have been, by impression of elevated temperatures as result of the basalt emplacement, most completely drained of volatile substances (water included) of its own environs and of the depths of its origin, so that the concluding volcanic manifestations, if they reach the real surface, may have poured out on the air without sensible explosional activity, thus contributing to build up the mysterious basaltic shield volcanoes.

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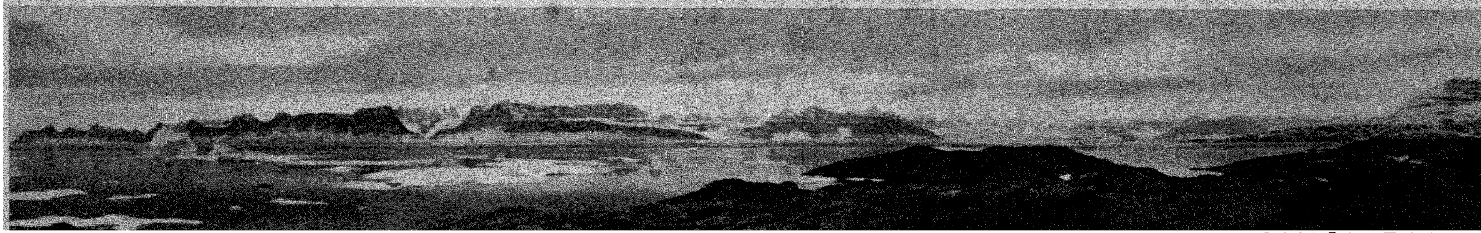
Færdig fra Trykkeriet den 24. Maj 1944.

Telefot. Leica. H. G. B. 1933.

1. Neill Klinter from Vardekløft to Moskusoksekløft (ab 6 km) seen from the opposite shore of Hurry Fjord. Basalts sills 1, 2, 3, and 4 (centre).



Telefot. Leica. H. G. B. 1934.

2. The basalt pile south of the line Kap Brewster—Kap Stevenson at its western border. View from Hekla Havn at Danmarks Ø. Length of the panorama about 60 km; distances: to eastern border (Kap Stevenson) ab. 38 km, to the central part ab. 24 km and to the basalt of eastern Gaaseland, reposing at 400 m on the crystalline basement, ab. 15 km.